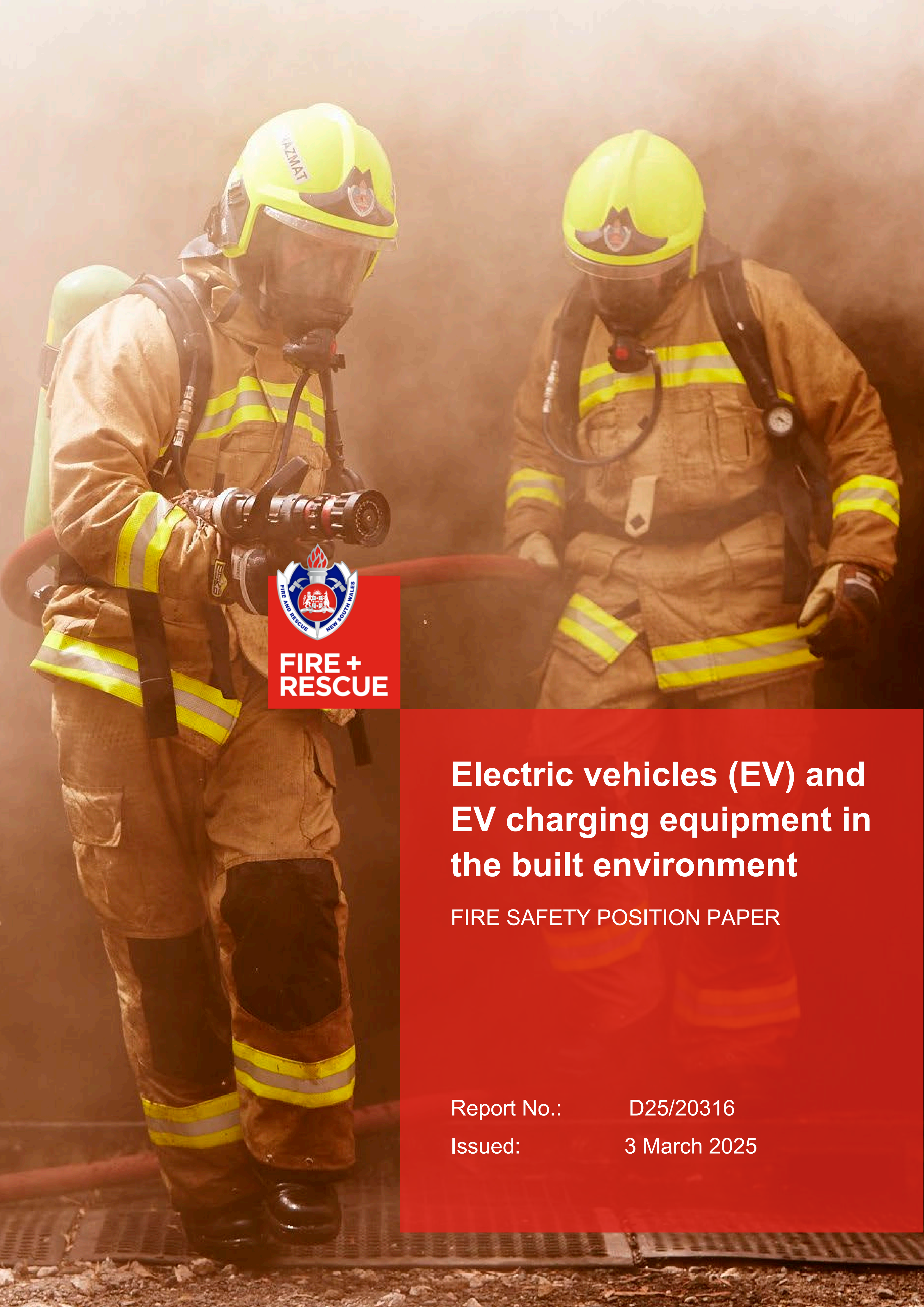

FIRE + RESCUE

Electric vehicles (EV) and EV charging equipment in the built environment

FIRE SAFETY POSITION PAPER

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EXECUTIVE SUMMARY

A safe transition towards cleaner alternative and renewable energy sources requires consideration of the safety of the community and emergency responders who are tasked with responding when incidents involving these technologies occur.

The prevalence of electric vehicle (EV) fires is currently low in most jurisdictions in comparison with fires involving traditionally fuelled vehicles, however fire and emergency services have identified a number of operational needs and research and knowledge gaps that need to be addressed with urgency as the electrification of the vehicle fleet accelerates worldwide.

The unique hazards associated with lithium-ion batteries (LiBs), including thermal runaway, vapour cloud ignition, extreme fire behaviour, stranded electrical energy, electrical risks from charging, extinguishment challenges, toxic emissions and fire effluents, and secondary ignitions, all render EV incidents more challenging for emergency responders, requiring extra precautions, resources, and training to safely and effectively manage them.

As the current deemed-to-satisfy (DtS) clauses in the National Construction Code (NCC) do not adequately address the special problems of firefighting associated with EVs, Fire and Rescue NSW (FRNSW) considers the E1D17 and E2D21 special hazard provisions in NCC 2022 to be appropriate for application to EV parking and charging in buildings. These ‘special hazards’ clauses require consideration of special characteristics of the building or use of the building that require additional mitigating measures to facilitate safe fire brigade intervention due to the DtS Provisions not adequately addressing the risk. The position is informed by current knowledge and as the research and evidence continues to develop, FRNSW’s position will evolve as appropriate.

CONTENTS

ABBREVIATIONS USED

A	Ampere, amp
ABCB	Australian Building Codes Board
AC	Alternating current
AFAC	Australasian Fire and Emergency Service Authorities Council
BCA	Building Code of Australia
BESS	Battery energy storage system
BEV	Battery electric vehicle
BMS	Battery Management System
BSC	Battery Stewardship Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	Direct current
DtS	Deemed-to-Satisfy
ERG	Emergency response guide
ESC	External short circuit
ESIP	Emergency Services Information Pack
EV	Electric vehicle
FCEV	(Hydrogen) fuel cell electric vehicle
FRNSW	Fire and Rescue New South Wales
FRL	Fire Resistance Level
HAZMAT	Hazardous materials, hazardous materials response
HEV	Hybrid electric vehicle
HF	Hydrogen fluoride, hydrofluoric acid
HRR	Heat release rate
HV	High voltage
ICEV	Internal combustion engine vehicle
ISC	Internal short circuit
kWh	kilowatt-hour
LCO	Lithium cobalt oxide ($LiCoO_2$)
LFP	Lithium iron phosphate ($LiFePO_4$)

LiB	Lithium-ion battery
$LiPF_6$	Lithium hexafluorophosphate
LiPo	Lithium-ion polymer
LMO	Lithium manganese oxide ($LiMn_2O_4$)
LMP	Lithium metal polymer
NCA	Lithium nickel cobalt aluminium oxide ($LiNiCoAlO_2$)
NCC	National Construction Code
Ni-Cd	Nickel-cadmium
NiMH	Nickel-metal hydride
NMC or NCM	Lithium nickel manganese cobalt ($LiNiMnCoO_2$)
NSW	New South Wales
OCC	Oxygen consumption calorimetry
PHEV	Plug-in hybrid electric vehicle
pHRR	Peak heat release rate
PIP	Pre-incident plan
PF_5	Phosphorous pentafluoride
POF_3	Phosphoryl fluoride
ppm	parts per million
RPAS	Remotely operated aircraft system
RTC	Road traffic collision
SCBA	Self-contained breathing apparatus
SoC	State of charge
THR	Total heat release
V	Volt, voltage
Vac	Volts alternating current
Vdc	Volts direct current
Wh	watt-hour

INTRODUCTION

BACKGROUND

Fire and Rescue New South Wales (FRNSW) conducts research that informs the development of doctrine and training to prepare our firefighters for new and emerging risks in the community. It also provides an evidence-base from which we can minimise the potential consequences of fires and other emergencies through offering technical advice, assessment and consultancy services to the building and fire safety industries, and guidance to regulatory authorities and government agencies to ensure that fire safety measures are commensurate with identified risks.

FRNSW is highly supportive of a safe transition towards cleaner alternative and renewable energy sources, and the replacement of internal combustion engine vehicles (ICEVs) with electric vehicles (EVs), which include battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel cell electric vehicles (FCEVs).

Energy storage in the form of lithium-ion batteries (LiBs) has become increasingly used and accepted in a wide range of applications across the consumer, residential, commercial, industrial, and transport sectors. The technologies used in portable electronic devices such as e-cigarettes and vapes, mobile phones, tablets, laptops, and power tools, are now being used in increasingly larger applications, including electric scooters, electric bikes, EVs, and battery energy storage systems (BESS) for residential, community, commercial and grid-scale applications. The higher energy density of LiBs, generally in the 120-180 Wh/kg range compared with 30 Wh/kg for lead-acid, 50 Wh/kg for nickel-cadmium (Ni-Cd) and 60-70 Wh/kg for nickel-metal hydride (NiMH), and improvements in manufacturing efficiencies and costs in the past two decades have established LiB chemistries as the preferred choice for EV applications[1]. LiBs refer to a family of batteries in which the cathodes comprise of various oxides of lithium. Some common examples include lithium cobalt oxide ($LiCoO_2$ or LCO), lithium nickel manganese cobalt ($LiNiMnCoO_2$, NMC or NCM), lithium nickel cobalt aluminium oxide ($LiNiCoAlO_2$ or NCA), lithium manganese oxide ($LiMn_2O_4$ or LMO), lithium iron phosphate ($LiFePO_4$ or LFP) and lithium-ion polymer (LiPo).

The Battery Stewardship Council (BSC) estimates[2] that whilst demand for other battery types will remain steady or decline, LiB sales are expected to increase six-fold to over 600,000 tonnes per year by 2050. These estimates are largely based on the projected rise in demand for EVs and BESS in this period.

EVs made up 9% of new vehicle sales in NSW in 2023[3], a 143% increase on the previous year. This figure is slightly higher than the national average at 8.5%. EV's currently make up about 3% of NSW's road vehicle fleet with around 65,000 BEVs, 175,000 HEVs (including PHEVs) and a small number (73) of FCEV registered in NSW[4].. The State of NSW also has a growing number of public charging locations. The NSW Electric Vehicle Strategy[5] has been designed to increase EV sales to 52% by 2030-31 and includes an investment of $209 million to boost the EV charging network. The CSIRO estimates[6] that EVs could account for 99% of the Australian vehicle fleet by 2045.

As with all new technologies, considerations must be given to the safety of the community and to the emergency responders who are tasked with responding when incidents occur. FRNSW recorded a 66% increase in fires caused by LiBs between 2022 and 2023, and an injury rate four (4) times higher than overall non-LiB related fires attended[7]. EV battery fires constituted 1.5% of LiB-related incidents. FRNSW is aware of 29 vehicle model recalls in Australia since November 2020 that were related to the battery systems of EVs, affecting over 7000 units[8].

On 29 April 2024, FRNSW released a fire safety position statement[9] (last updated 4 June 2024) on EV's and EV charging equipment that endorsed the position 'Electric Vehicles (EV) and EV charging equipment in the built environment'[10], published by the Australasian Fire and Emergency Service

Authorities Council (AFAC) in December 2022, as the appropriate guidance to practitioners who design and certify any Class 2-9 building that incorporates EV parking and/or charging.

Ver 02 of the Position Statement dated June 2024 is shown below. A Position Statement Summary is also available and has been included in Appendix A.

FRNSW endorse the position on [Electric Vehicles (EV) and EV charging equipment in the built environment]() as published by the Australasian Fire and Emergency Service Authorities Council (AFAC), as the appropriate guidance to practitioners who design and certify any Class 2-9 building that incorporates EV parking and/or charging.

FRNSW consider EVs and EV charging stations to be special hazards under E1D17 and E2D21 of the National Construction Code (NCC) 2022. As such, the certifier should identify what additional provisions are being provided, if any, and whether the fire safety measures in the building are commensurate to the hazards and risk(s) associated with the proposed EV parking and/or charging, when certifying any related building application.

***Note:** FRNSW considers incidents involving electric vehicles (EVs) and EV infrastructure to currently be low frequency, but potentially high consequence, incidents that require enhanced fire safety measures in place to facilitate safe and effective fire brigade operations.*

FRNSW consider that all aspects of the AFAC Position should be considered and addressed. In conjunction with the AFAC position, FRNSW recommend that EV parking and/or charging be:

- *located externally or in open air where possible.*
- *if located internal to a building, the carparking area should:*
  - *be protected by an automatic fire sprinkler system with a performance equivalent to a system complying with AS 2118.1 or AS 2118.6; and*
  - *not apply concessions to fire resistance levels (FRLs) that may be provided within the NCC deemed-to-satisfy provisions.*
- *protected by fire hydrant coverage.*

Any request for consultation or referral to FRNSW relating to any building that intends to incorporate EV parking and/or charging, should adequately identify the hazards and risks and demonstrate how they are being addressed within the design. The 'recognised person' should address the special hazards and how the provisions of this position statement and the AFAC Position have been considered and addressed.

***Note:** A 'recognised person' means a person who is both an accredited practitioner (fire safety) and a fire safety engineer under the [Environmental Planning and Assessment (Development Certification and Fire Safety) Regulation 2021]().*

FRNSW's position statement has garnered interest and opposition[11,12], with several organisations and advocacy groups contesting the use of the special hazards clauses in the NCC for EVs due to the estimated cost implications of any additional fire safety measures required to address the risks.

Both the AFAC and FRNSW positions on EV are informed by current knowledge, research, and learnings from incidents involving LiBs and associated devices and equipment, including EVs. The research has been driven by an increase in the availability of LiB powered devices and equipment, and the experience of fire and emergency services worldwide in responding to incidents involving these technologies. Presently there are several gaps in understanding EV fires and the appropriate mitigation measures required to safely and effectively manage them. As the research and evidence continues to develop, FRNSW's position will evolve as appropriate. This paper outlines the basis of the current position.

CURRENT NCC REQUIREMENTS AND THE 'SPECIAL HAZARDS' CLAUSES

Volume One of the NCC[13] sets out the minimum Building Code of Australia (BCA) requirements for new Class 2 to 9 buildings. In NCC 2022, which came into effect on 1 May 2023, provision J9D4 was introduced in *Section J Energy efficiency*, requiring dedicated electrical infrastructure for EV charging equipment in carparks associated with Class 2, 3, 5, 6, 7b, 8 and 9 buildings. For Class 2 buildings, the electrical infrastructure must be sized adequately to support the future installation of charging equipment in 100% of car parking spaces.

NCC 2022 does not specify any fire safety provisions specific for alternative and renewable energy installations in buildings, including EVs and EV charging equipment. Current deemed-to-satisfy (DtS) fire safety provisions for carparks in the NCC are based on aspects such as the building classification, the rise in storeys and/or effective height and whether the carpark is open-deck or enclosed.

Modern day vehicles are, on average, larger, heavier, and contain more synthetic and combustible materials than vehicles built in the 20th century[14,15], contributing to more intense fires that produce larger amounts of toxic fire effluents. In recent years, some high-profile fires in carparks around the world (*Stavanger Airport*[16], *Märsta*[17], *Luton Airport*[18], *Incheon*[19]) and cargo ships (*Felicity Ace*[20], *Fremantle Highway*[21]) have highlighted the speed at which fires involving modern vehicles can propagate in parking arrangements without adequate separation, compartmentation and fire protection. While investigations revealed that some of these incidents may not have started in EVs, they were likely to be among the vehicles that became involved in these fires.

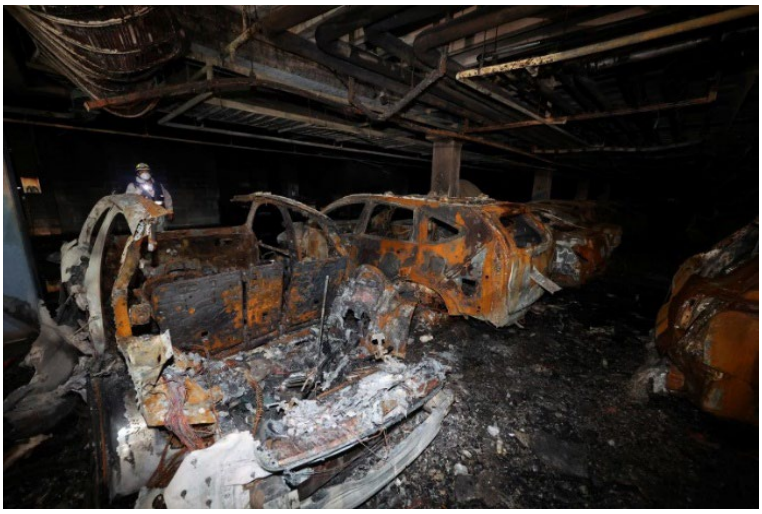

FIGURE 1 AN ELECTRIC VEHICLE WENT INTO THERMAL RUNAWAY, STARTING A FIRE IN THE BASEMENT CAR PARK OF AN APARTMENT BUILDING IN INCHEON, SOUTH KOREA ON 1 AUGUST 2024. APPROXIMATELY 140 VEHICLES WERE DAMAGED IN THE FIRE (SOURCE: REUTERS 2024[22])

FIGURE 2 A FIRE BROKE OUT ON THE FELICITY ACE ON 16 FEBRUARY 2022 IN THE NORTH ATLANTIC OFF THE COAST OF PORTUGAL (SOURCE: REUTERS 2022[20]). THE SHIP WAS CARRYING 3965 NEW VEHICLES FROM GERMANY TO THE USA. THE ORIGIN OF THE FIRE HAS REPORTEDLY BEEN ATTRIBUTED TO THE LIB FROM A PORSCHE[23].

Thermal runaway in an EV battery, even if not the origin of the fire, can accelerate fires that occur in carparks and locations where vehicles are in close proximity, and presents an added complication for smoke hazard management, fire suppression, and firefighting. When on charge, batteries are at risk of failure due to overheating, overcharging, charging imbalance or electrical faults, and cells are likely to be carrying a higher charge if they fail. For emergency responders, charging adds complexity to an incident as there is a need for (often manual) electrical isolation prior to extinguishment, under challenging conditions that can involve extreme heat and minimal visibility in enclosed areas.

Since 2021, the Australian Building Codes Board (ABCB) has commissioned several desktop studies to examine the risk of EVs and general fire safety in carparks[24,25,26,27]. Burke (2021)[2424] presented a number of conflicting ideas, stating that while "*It is not certain that carpark fire safety design standards remain fit-for-purpose*" in the context of modern cars, and "*It would not be prudent to wait until rising accident trends confirm this before acting*", "*EV charging equipment is not expected to have a significant impact on carpark fires or fire severity*" and that "*NCC requirements do mitigate the hazards and risks of EV charging in building carparks*". Following this report and some further consultation with stakeholders the J9D4 charging infrastructure requirements were included in NCC 2022. AFAC submitted comments on the NCC 2022 Public Comment draft in October 2021 raising concerns regarding the lack of fire safety considerations in the proposed EV charging provisions.

The ABCB held some EV readiness roundtable discussions in August 2022 and commissioned consultancy EV FireSafe[2525] to advise on a series of "close to cost neutral" and "low visual impact" safety measures for emergency responder safety around EV charging. AFAC members were generally unable to endorse the EV FireSafe report and recommendations and felt that *"most of the recommendations in level 1 are already required through electrical installation standards and WHS Acts, and AFAC would have preferred to see the 3 levels based on risk, with the application of the level depending on the risk profile of the building, rather than 3 levels of cost implication for building owner/developers"* and *"given the unique characteristics of lithium-ion battery fires, the consequence element of 'Risk' has largely been disregarded"* [28]. The ABCB recommendations[29] that resulted from the consultation included the installation and inclusion of master isolation switches, break glass fire alarms, collision protection, assessment of proximity to evacuation routes and flammable risks, specialist assessment for complex buildings, AS/NZS 3000 Appendix P and RCM tick compliance, smart charging, regular maintenance, and the provision of placards, block plans, directional signage, Emergency Services Information Pack (ESIP) and Pre-Incident Plan (PIP). These recommendations were published with minimal guidance or specifications for implementation. It is also noted that the ABCB Advisory Notice provides a link to the full EV FireSafe Report on the EV FireSafe website, however only a description is currently provided and not the full report.

Following this work, the ABCB commissioned engineering firm Arup to conduct a literature review[26] on fire safety in modern car parks, which was later peer-reviewed by Warrington Fire[27], to support its investigation into the adequacy of car park fire safety provisions in the NCC. Currently NCC 2022 allows some concessions for open-deck and sprinkler-protected carparks with regard to items such as sprinkler protection and fire resistance levels. Arup found that the existing body of evidence suggests the current building codes are not appropriate for modern vehicles. As a result, the NCC 2025 public comment draft[30] removes some concessions, however provisions for EV-specific hazards have not been included.

The NCC does however include two provisions, the ‘special hazards’ clauses, that require consideration of special characteristics of the building or use of the building that require additional mitigating measures to facilitate safe fire brigade intervention due to the DtS Provisions not adequately addressing the risk. The Guide to NCC Volume One 2019 under E1.10 (the previous reference for E1D17) states that “The other Deemed-to-Satisfy Provisions of Part E1 set out the required firefighting equipment and co-ordination facilities required in a building to deal with “expected” or “usual” hazards. Whilst AFAC and FRNSW do not consider the presence of EVs and EV charging to be particularly *unexpected* or *unusual* in carparks, fires involving EV batteries and EVs connected to charging can result in hazards in carparks that are different to fires involving more conventional vehicles and present special problems of firefighting.

Part E1 *Firefighting equipment* in NCC Volume One focuses on the provision of firefighting equipment to: (a) safeguard occupants from illness or injury while evacuating during a fire; (b) provide facilities for occupants and the fire brigade to undertake fire-fighting operations; and (c) prevent the spread of fire between buildings.

The DtS provision E1D17 requires the installation of additional fire safety measures where special hazards exist. The clause does not specify what the special provisions must be, requiring each case to be assessed on its own merits.

> **E1D17 Provision for special hazards**
>
> Suitable additional provision must be made if special problems of fighting fire could arise because of—
>
> (a) the nature or quantity of materials stored, displayed or used in a building or on the allotment; or
>
> (b) the location of the building in relation to a water supply for fire-fighting purposes.

Part E2 *Smoke hazard management* focuses on safeguarding occupants from illness and injury from the products of combustion including smoke and toxic gases. It provides automatic warning of the presence of smoke or fire, and measures to ensure conditions within evacuation routes remain tenable long enough for occupants to evacuate safely.

The DtS provision E2D21 requires careful consideration in the application of smoke hazard management provisions of the NCC and additional smoke hazard management measures where some special hazards exist. The clause does not specify what the special provisions must be, requiring each case to be assessed on its own merits and additional safeguards provided as necessary.

E2D21 Provision for special hazards

Additional smoke hazard management measures may be necessary due to the—

(a) special characteristics of the building; or

(b) special function or use of the building; or

(c) special type or quantity of materials stored, displayed or used in a building; or

(d) special mix of classifications within a building or *fire compartment*,

which are not addressed in E2D4 to E2D20.

AFAC and its members, including FRNSW, consider the E1D17 and E2D21 provisions in NCC 2022 to be appropriate for application to EV parking and charging in buildings, whilst the DtS Provisions do not adequately address the risks.

In a recent NSW Parliamentary Inquiry into 'Electric and hybrid vehicle batteries'[31] the Joint Standing Committee on Road Safety (Staysafe) recommended "*That the Building Commission NSW work with the Australian Building Codes Board to review building codes to ensure that EV fire risks are mitigated in new and existing buildings.*" (Recommendation 4[32]).

SPECIAL HAZARDS ASSOCIATED WITH LIB AND EV FIRES

All fires are hazardous and must be contained or extinguished effectively to minimise the risks of injury and loss. LiB fires are considered distinctive and non-conventional in the sense that they can be spontaneous, highly volatile and self-sustaining.

Fires involving large LiBs can require significant fire service resources and intervention over several hours or days, and have the potential to cause significant injuries, damage to buildings and infrastructure, and environmental pollution.

EVs contain large high voltage (HV) battery packs that comprise hundreds or thousands (depending on format) of individual LiB cells connected in series and in parallel to provide the range and power required. EVs incorporate a range of safety features designed to ensure the safety of occupants and responders, however unfortunately these will not always guarantee that a battery will not fail or prevent external factors impacting on the battery.

The unexpected and unusual hazards and special problems of firefighting that warrant the application of the ‘special hazards’ clauses in the NCC include:

THERMAL RUNAWAY, VAPOUR CLOUD IGNITION, AND EXTREME FIRE BEHAVIOUR

Thermal runaway in a LiB is an exothermic chemical reaction involving intense, cascading and uncontrollable heating of a battery cell or multiple cells within a battery pack, often accompanied by the pressurised release of large volumes of toxic, corrosive, flammable, and potentially explosive vapours and gases, and intense, directional, jet-like flames.

Thermal runaway in EV batteries can result from:

- Electrical issues or faults, e.g. failure of the battery management system (BMS), leading to overcharge, over discharge, or cell imbalance, or internal short circuit (ISC) or external short circuit (ESC) due to water ingress, corrosion or degradation of electrical components.
- Mechanical abuse, e.g. from impact from road debris or from deformation of the battery pack during a high-speed crash.
- Thermal abuse, e.g. from exposure to extreme heat or fire from an external source, or failure of the cooling system
- Cell defects, ageing and deterioration.

LiB vapours and thermal runaway gases contain high concentrations of flammable hydrogen and hydrocarbons that may lead to explosions in confined spaces[33]. The volume of toxic and flammable gases produced during thermal runaway varies with LiB cell chemistry, cell format or geometry, state of charge (SoC), and failure mechanism. Studies have reported off-gas volumes up to 5.23 Litres per Wh[34]. Note that battery packs in BEVs can range up to 120 kWh (120,000 Wh) in stored energy.

STRANDED ELECTRICAL ENERGY AND ELECTRICAL RISKS FROM CHARGING

Large battery packs present significant fire and electric shock risks when involved in emergencies. Even when disconnected, batteries may still hold a significant amount of charge and emergency responders must be aware of the presence of HV components and cabling when working on or around vehicles containing large batteries, especially during rescue and extrication, but also during monitoring and overhaul after a thermal event[35].

EVs generally include both high and low voltage battery packs. Low voltage batteries generally operate between 12 and 48 Vdc depending on the application. HV battery packs operate between 200 and 900 Vdc. EV traction motors generally run on AC electricity and an inverter is used to convert the DC voltage supply of the battery. EV chargers supply AC voltages between 240 and 415 Vac, while DC fast chargers can currently supply output voltages up to 1000 Vdc. These levels are well above the voltage levels that are considered safe for humans. When a HV battery is damaged and the electrical isolation system is compromised, anyone who is exposed to energised components can become part of the HV circuit and suffer serious injury or death[36].

EXTINGUISHMENT CHALLENGES

Fires involving the high-voltage LiBs in EVs are highly complex. Traditional methods of fire extinguishment are largely ineffective as: i) Oxygen is a by-product of the thermal decomposition of the cathode materials in LiBs and hence LiB fires cannot be starved of oxygen or smothered; and, ii) Water in large quantities is required to prevent further propagation of thermal runaway in LiBs, however effective extinguishment is difficult due to the lack of direct access to battery cells.

The HV battery in a BEV is usually mounted in the floor pan between the wheel axle and protected by a robust (usually steel or aluminium) casing. Tesla advises[37] that it can take between 3000-8000 gallons (11,356-30,283 litres) of water applied directly to the battery to fully extinguish and cool down an EV battery fire. EV safety training videos[38] show the need to lift and prop vehicles with stabilising tools for better access to the vehicle underside. Complicating factors include space requirements, a lower centre of mass, and specific lift points to avoid stressing the HV battery pack.

FIGURE 3 AN ELECTRIC VEHICLE PROPPED UP WITH STABILISING STRUTS FOR BATTERY COOLING (SOURCE: BROCK ARCHER 2019[ERROR! BOOKMARK NOT DEFINED.]**).**

An additional consideration in LiB fire extinguishment is the need to monitor and manage large quantities of contaminated fire water, firefighting foams or other extinguishing media, which if uncontained can pollute soil, ground water and nearby waterways.

In recent years there has been a proliferation of products marketed worldwide and in Australia for use in LiB and EV incidents. Products include novel extinguishing agents and delivery systems, fire blankets, undercar cooling nozzles or pancake nozzles, high-pressure water blades or cutting extinguishers, piercing nozzles, specialist containment systems and overpacking media, EV arresting plugs and DC voltage detection equipment[39,40,41,42,43,44,45,46,47].

Without the necessary certification and independent testing in Australia to evidence and compare product efficacy and safety in the context of local fire and emergency service requirements, agencies are unable to make appropriate evidence-based decisions. The acquisition of new equipment requires a rigorous selection process that not only includes an assessment of the products' efficacy and efficiency against like- and existing equipment and procedures, but some additional considerations include ongoing costs, logistics, stowage, shelf-life, maintenance, safety of deployment, and changes to procedures, doctrine and training.

Both the Fire Protection Association (FPA Australia) and CSIRO have released advisory notices[48,49] to clarify that no applicable standards exist in Australia for portable LiB fire extinguishers. Similarly, the Australasian Fire and Emergency Service Authorities Council (AFAC) has circulated an advisory note[50] to reinforce this message, including fire blankets marketed for LiB and EV fires.

TOXIC EMISSIONS AND FIRE EFFLUENTS

In addition to typical combustion gases such as carbon monoxide (CO) and hydrogen cyanide (HCN), LiB fires contain some highly toxic and corrosive compounds specifically related to the chemistry of the electrolytes, solvents and binding agents used in LiBs. The compounds of most concern include fluoride compounds, which are highly toxic.

Lithium hexafluorophosphate ($LiPF_6$) is the most used lithium salt in commercial LiB electrolytes[51,52]. When $LiPF_6$ decomposes it forms phosphorous pentafluoride (PF_5), a colourless, poisonous, non-flammable gas with a pungent odour that is extremely irritating to skin, eyes and mucous membranes. Inhalation of PF_5 is acutely toxic and can cause pulmonary oedema[53]. On exposure to water or steam, both $LiPF_6$ and PF_5 will decompose to hydrogen fluoride (HF) and phosphorus oxyfluoride (or phosphoryl fluoride, POF_3). While the toxicity of POF_3 is not known, the compound readily hydrolyses to form additional HF, which is known to be highly toxic and corrosive. HF is a colourless, fuming liquid or gas with a strong, irritating odour and is highly corrosive to metals and tissue. It is highly toxic by ingestion and inhalation, and exposure to fumes or very short contact with HF in liquid form may cause severe painful burns, deep-seated ulceration and severe and rapid hypocalcaemia[54]. The peak limit for HF exposure (maximum 15 minutes) is 3 ppm or 2.6 mg/m^3 [55]. Studies have measured HF concentrations of up to approximately 190 mg per Wh[52] or 39 mg per g lost[56] in LiB fires, with the concentration increasing inversely with SoC.

SECONDARY IGNITIONS

Once the flames from a LiB fire are extinguished or controlled, secondary ignitions involving other battery cells can occur without warning some time after the initial event, potentially during recovery, transport, storage, and disposal.

EVs that have been damaged in a fire, a collision, or a storm or flooding event, have been known to ignite due to subsequent battery failure and must be monitored during transport, and adequately separated from any exposures or other combustibles during storage. Some jurisdictions abroad have resorted to deploying purpose-built containment and immersion units to hoist and remove EVs from incidents[57]. Incorrect storage of defective EV batteries has resulted in a significant fire in NSW[58].

FIGURE 4 AN EV BEING CRANED INTO A CONTAINER (LEFT) AND IMMERSED IN WATER (RIGHT) IN LEUVEN, BELGIUM FOLLOWING A THERMAL RUNAWAY INCIDENT (SOURCE: OOST VLAAMS BRABANT 2021[59])

PREVALENCE OF EV FIRES

RISK

When considering risk, prevalence is a factor that must be considered along with the hazards and potential consequences. It is important to note that while not all fires involving LiB-powered EVs start from the high-voltage battery, emergency responders need to take extra precautions due to the unique hazards associated with EVs and the sustained risk of thermal runaway. For any vehicle identified as having a HV battery, these extra precautions may include the need for:

- a safe approach and establishment of an adequate exclusion zone,
- model identification and accessing *Rescue Sheets* and/or *Emergency Response Guides (ERGs)* for handling information, locations of the HV battery pack and HV components, and shutdown or immobilisation procedures,
- disconnection from any charging equipment,
- monitoring for signs of thermal runaway,
- ventilation of the vehicle cabin or enclosure in the case of vapour build up,
- extinguishment including protection of the battery pack and preventative cooling, and
- ongoing monitoring of the battery pack, including during investigations, overhaul, transportation and storage.

A fire that does not initially involve the LiB in an EV or does not originate in an EV but is adjacent to one, can still be highly protracted and complex as a result. Firefighters must be able to recognise EVs and large LiB-powered devices or equipment in a fire incident and protect them from exposure that may lead to a thermal runaway reaction.

This section will consider the current prevalence of EV fires, however it is important to note that comparing the incident rates between EVs and ICEVs only does not give a true reflection of risk. The potential consequences also need to be considered which is a current major challenge with these new technologies.

INTERNATIONAL DATA

EV FireSafe reported a total of 511 EV (BEV and PHEV) battery fires between 2010 and 30th June 2024 globally[60]. The often-cited source of EV fire statistics suggests that EVs are approximately 83 times less likely to catch fire than ICEVs, stating: *"Our intial [sic] research findings, based on global EV battery fires from 2010-2020, indicate a 0.0012% [chance] of a passenger electric vehicle battery catching fire. While it's difficult to find a similar stat for internal combustion engine (ICE) passenger vehicles globally, a range of country-based reports we found suggest there is a 0.1% chance of an ICE vehicle catching fire."* [61] It is unclear whether the probabilities stated are calculated per vehicle registrations, per vehicle sales, or per vehicle distance travelled, which are common measurands. However the evidence that is cited by EV FireSafe[61] includes a report of one Tesla EV fire per 205 million miles travelled vs one every 19 million miles for all vehicles in the US[62] (10.8 times greater chance of ICEV fire per mile travelled), a report of 0.9 times per 10k EV vs 2 per 10k ICEVs in China[63] (2.2 times greater chance of ICEV fire per vehicle), and a US insurer's comparison[64] of 25 BEV fires per 100k vehicle sales vs ~3,475 HEV fires (HEV fires 139 times more likely) and ~1,530 ICEV fires (ICEV fires 61 times more likely).

Conversely, a recent report by Worldmetrics[65] claimed that: *"In the US, electric vehicle fires occur at a rate of 2.19 fires per 10,000 registered vehicles per year"* and *"The risk of lithium-ion battery fires in electric vehicles is 9 times higher than in traditional vehicles"*. The sources of data were not available for review and could not be verified.

In recent years there has been an increase in awareness of LiB fire incidents and several jurisdictions have commenced reporting official data on EV fires, with varying levels of detail. Countries such as Norway, Sweden, the Netherlands, and the People's Republic of China (China), which have some of the highest EV adoption rates in the world, have made reports available in their native languages

A review of publicly available data (machine translated to English where required) from official government and fire service sources was conducted to gauge the trends in EV fire occurrence. The analysis includes a comparison of EV and ICEV fire rates where separate data was available or could be calculated. Some sources point out that only incidents which have been classified as 'vehicle fires' have been included in the data, which excludes some 'structure fires' that may have involved or started from a vehicle, and road traffic collisions (RTCs) in which the vehicle(s) subsequently caught fire. Additionally, the incident data does not include the number of vehicles in each incident when more than one is involved.

NORWAY

Norway is known for having the highest EV adoption rate in the world. Norwegian fire statistics published by the Directorate for Social Security and Emergency Preparedness (Direktoratet for Samfunnssikkerhet og Beredskap, DSB)[66] and passenger vehicle registration data from Statistics Norway (Statistisk Sentralbyrå)[67] show that EV fire rates have remained steady amidst the doubling of registrations since 2019, averaging around 4.5 fires per 100,000 registrations.

Interestingly for ICEVs, the steady decline in petrol vehicle registrations has seen the fire rate climb from 24.6 to 29.8 fires per 100,000 registrations in 2023. The five- to seven-fold difference in fire rates may reflect an ageing ICEV fleet as it becomes replaced by new BEVs. Note that diesel-fuelled vehicles have remained popular during recent years and continue to dominate the Norwegian vehicle fleet at 45% in 2023.

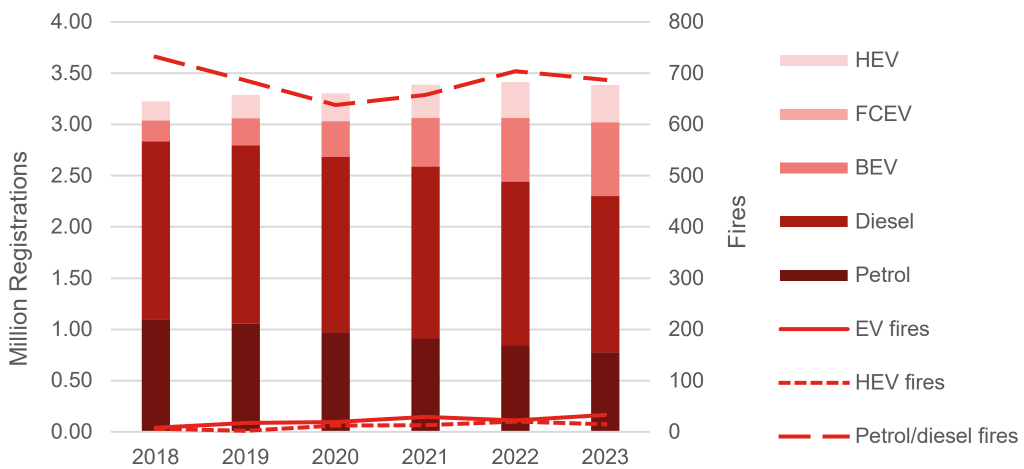

FIGURE 5 CHART SHOWING PASSENGER VEHICLE REGISTRATIONS (COLUMNS) AND VEHICLE FIRES (LINES) BY FUEL TYPE IN NORWAY BETWEEN 2018-2023.

TABLE 1 ESTIMATED EV AND ICEV FIRE INCIDENCE RATES FROM AVAILABLE NORWEGIAN DATA.

	2018	2019	2020	2021	2022	2023
EV fires	14	19	31	42	42	48
EV registrations	390,365	495,030	622,210	800,591	970,899	1,082,359
EV fire rate per 100,000 registrations, per year	3.6	3.8	5.0	5.2	4.3	4.4
ICEV fires	732	686	638	658	704	687
ICEV registrations	2,836,623	2,793,696	2,682,332	2,587,658	2,443,092	2,302,487
ICEV fire rate per 100,000 registrations, per year	25.8	24.6	23.8	25.4	28.8	29.8
ICEV fire rate : EV fire rate	7.2 : 1	6.4 : 1	4.8 : 1	4.8 : 1	6.7 : 1	6.7 : 1

SWEDEN

A recent report from the Swedish Civil Contingencies Agency (Myndigheten för Samhällsskydd och Beredskap, MSB) on non-arson related EV fires from 2018-2023[68] demonstrated slightly higher average rates than those of Norway over the period. Data on passenger vehicle fires[69] and registrations[70] show that the rate of ICEV fires was 10 times greater than EV fires in 2023.

TABLE 2 ESTIMATED EV AND ICEV FIRE INCIDENCE RATES FROM AVAILABLE SWEDISH DATA.

	2018	2019	2020	2021	2022	2023
EV fires	8	7	20	24	23	38
EV registrations	156,331	207,904	308,485	452,413	610,716	754,776
EV fire rate per 100,000 registrations, per year	5.1	3.4	6.5	5.3	3.8	5.0
ICEV fires	-	-	-	-	1,984	2,145
ICEV registrations	4,714,452	4,680,000	4,635,582	4,534,337	4,369,827	4,222,387
ICEV fire rate per 100,000 registrations, per year	-	-	-	-	45.4	50.8
ICEV fire rate : EV fire rate	-	-	-	-	12.1 : 1	10.1 : 1

THE NETHERLANDS

The Netherlands Institute for Public Safety (Nederlands Instituut Publieke Veiligheid, NIPV) reported[71] 152 alternative fuel vehicle fire incidents involving 163 vehicles in 2023. This represented a 30% increase from 2022[72] and a 245% increase in incidents from 2021[73]. NIPV also reported that of the 259 plug-in EV incidents in 2021-2023, 37% involved EVs that were charging at the time. While data on ICEV fires in The Netherlands were not publicly available, EV fire incidence rates estimated from vehicle registration data published by the European Commission[74] reveal a significant departure from the Norwegian and Swedish figures, reaching over 17 EV fires per 100,000 registered vehicles in 2022 and 2023.

TABLE 3 ESTIMATED EV FIRE INCIDENCE RATES FROM AVAILABLE DUTCH DATA.

	2021	2022	2023
EV fires	62	117	152
EV registrations	533,289	668,878	862,326
EV fire rate per 100,000 registrations, per year	11.6	17.5	17.6

ENGLAND

CE Safety published[75] data sourced from Freedom of Information requests submitted to 50 fire and rescue services across the UK. Data received from 31 services mostly from English counties revealed a total of 118 EV/hybrid passenger car fires in the 2022/23 fiscal year. Official fire statistics from the UK Government Home Office[76] revealed that in the same period, road vehicle fires totalled 19,256 in England. Vehicle licensing statistics from the UK Department of Transport[77] were used to calculate the fire rates per 100,000 vehicles in Table 4 below.

TABLE 4 ESTIMATED EV AND ICEV FIRE INCIDENCE RATES FROM AVAILABLE ENGLISH DATA.

	FY 2022/23
EV fires	118
EV registrations	1,130,570
EV fire rate per 100,000 registrations	10.4
ICEV fires	19,138
ICEV registrations	32,827,630
ICEV fire rate per 100,000 registrations	58.2
ICEV fire rate : EV fire rate	5.6 : 1

PEOPLE'S REPUBLIC OF CHINA

In China, the world's largest EV market, the Research Office of the Chinese People's Political Consultative Conference (CPPCC) reported approximately 3000 new energy vehicle fires in 2022 in 13.1 million vehicles, stating that the rate of 0.03% was *"higher than the annual fire accident rate of traditional fuel vehicles"* and was expected to *"increase by about 30% in 2023"*[78]. The main causes were reportedly due to battery short circuit, overcharging and collisions. The following rates of EV fires and ICEV fires with respect to vehicle registrations in China can be estimated from the information published by the National Fire and Rescue Administration[79] and the Ministry of Ecology and Environment[80]. EVs and ICEVs in China had similar fire rates of around 5 fires per 100,000, over the first quarter in 2022.

TABLE 5 ESTIMATED EV AND ICEV FIRE INCIDENCE RATES FROM AVAILABLE CHINESE DATA.

	2021	2022
EV fires in Q1	485	640
Projected EV fires in year	1,940	2,560
EV registrations	7,840,000	13,100,000
EV fire rate per 100,000 registrations, per year	24.7	19.5
ICEV fires	14,199	14,583
Projected ICEV fires in year	56,796	58,332
ICEV registrations	294,728,367	306,412,195
ICEV fire rate per 100,000 registrations, per year	19.3	19.0
ICEV fire rate : EV fire rate	0.78 : 1	0.97 : 1

SOUTH KOREA

In an April 2024 press release[81], the National Fire Agency (NFA) in South Korea shared some detailed data on vehicle fires in 2021-2023 that included data on EV fires. This followed a NFA press release in August 2023[82] which indicated that the fire occurrence rate for EVs was 0.01%, compared with 0.02% for ICEVs. The findings indicated that the data for EVs presented included BEVs only. Vehicle registration data from the Ministry of Land, Infrastructure and Transport[83] was used to calculate the comparative rates presented in Table 6 based on the fire data available.

The detailed South Korean data also revealed some further insights:

- While there were no deaths associated with the 139 EV fires in 2021-2023, the 13 injuries (9.4%) represented a 2.4 times greater likelihood than in ICEV fires (3.9%).
- EV fires cost on average ₩23.42M (~AU$25.8k) per incident compared with ₩9.53M (~AU$10.4k) per incident for ICEV fires, i.e. 2.4 times more.
- EV fires occurred whilst the vehicle was parked 47% of the time, while ICEVs were parked 27% of the time when they caught fire. In 2023, EVs were 1.6 times more likely to catch fire when parked than ICEVS, at 6.3 fires per 100,000 registered EVs compared 3.9 fires per 100,000 registered ICEVs (see Table 7). EVs were charging in 19% of the EV fire incidents.

TABLE 6 ESTIMATED EV AND ICEV FIRE INCIDENCE RATES FROM AVAILABLE SOUTH KOREAN DATA. NOTE: EV DATA INCLUDES BEV ONLY.

	2021	2022	2023
EV fires	24	43	72
EV registrations	231,443	389,855	543,900
EV fire rate per 100,000 registrations, per year	10.4	11.0	13.2
ICEV fires	3,517	3,637	3,736
ICEV registrations	24,679,658	25,113,223	25,405,301
ICEV fire rate per 100,000 registrations, per year	14.3	14.5	14.7
ICEV fire rate : EV fire rate	1.4 : 1	1.3 : 1	1.1 : 1

TABLE 7 EV AND ICEV FIRE INCIDENTS (AND INCIDENCE RATES PER 100,000 REGISTRATIONS) WHEN PARKED OR IN OPERATION, FROM SOUTH KOREAN DATA.

Year	ICEV					EV					
	In operation	Parked			ICEV total	In operation	Stopped or being towed	Parked			EV total
		Parking lot	Open space	All parked				Not charging	Charging	All parked	
2021	2,612 (10.6)	634 (2.6)	271 (1.1)	905 (3.7)	3,517 (14.3)	12 (5.2)	1 (0.4)	7 (3.0)	4 (1.7)	11 (4.8)	24 (10.4)
2022	2,673 (10.6)	700 (2.8)	307 (1.2)	1,007 (4.0)	3,680 (14.7)	22 (5.6)	1 (0.3)	10 (2.6)	10 (2.6)	20 (5.1)	43 (11.0)
2023	2,737 (10.8)	690 (2.7)	309 (1.2)	999 (3.9)	3,736 (14.7)	34 (6.3)	4 (0.7)	21 (3.9)	13 (2.4)	34 (6.3)	72 (13.2)

FIRE AND RESCUE NSW DATA

The incidence rate of fires involving LiBs and EVs in NSW is currently low but is rising. In the first half of 2024, 1 in every 40 fire or explosion incidents attended by FRNSW involved rechargeable lithium-ion batteries[84], an increase from 1 in every 100 fires in 2022[85]. An analysis of vehicle fires attended by FRNSW between 1 January 2022 and 30 June 2024 found that there were 24 fires involving EV, and 6139 involving ICEV. Two (9%) of the EV fires and 3027 (49%) of ICEV fires were determined to be deliberate (arson) and were excluded from further analysis. NSW vehicle registration data from Transport for NSW (TfNSW)[86] was used to determine the fire rates in NSW (from FRNSW data only) (Table 8).

Some further insights from the NSW data included:

- That EV fire incidents took on average 8.5 hours to manage compared with 1.1 hours for ICEV fire incidents.
- The majority of vehicle fire incidents occurred on roads, streets, highways, motorways or tunnels (59% of EV incidents and 71% of ICEV incidents).
- The vehicle registration data showed that in 2023, 65% of EVs were less than 3 years old (2021 make or newer), compared with 15% of ICEVs.

TABLE 8 CALCULATED EV AND ICEV FIRE INCIDENCE RATES FROM FRNSW DATA.

	2022	2023	2024 (to June 30)
EV fires	11	6*	5^
EV registrations	138,324	202,578	246,935
EV fire rate per 100,000 registrations, per year	8.0	3.0	2.0 (half year)
ICEV fires	1,115	1,345	653
ICEV registrations	5,888,792	5,956,331	5,953,412
ICEV fire rate per 100,000 registrations, per year	18.9	22.6	11.0 (half year)
ICEV fire rate : EV fire rate	2.4 : 1	7.6 : 1	5.4 : 1

* In one of the six 2023 incidents classified as EV, three EVs were involved.
^ In one of the five 2024 incidents classified as EV, 12 EV batteries were involved

SUMMARY

An analysis of available official fire data from various jurisdictions revealed EV fire rates ranging between 3 and 25 fires per 100,000 registrations, and ICEV fire rates ranging between 15.8 and 58.2 fires per 100,000 registrations in 2021-2023, with the prevalence of ICEV fires up to 10 times greater than EV fires. The findings are summarised in Figure 6 below.

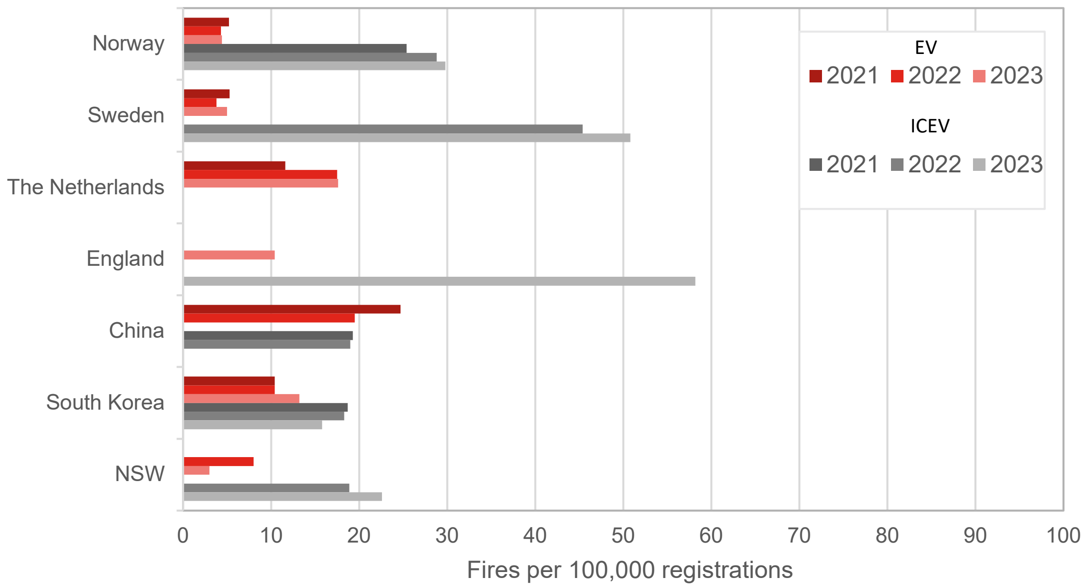

FIGURE 6 COMPARISON OF ESTIMATED EV AND ICEV FIRE RATES PER 100,000 REGISTRATIONS BETWEEN 2021 AND 2023 FOR VARIOUS JURISDICTIONS.

While there were no clear trends in the current data, it is interesting to note the regional similarities and differences.

- In Europe, while the Nordic countries of Norway and Sweden had similar rates of around 4-5 EV fires per 100,000 registered vehicles, the rates in the Netherlands were 2 to 4.6 times higher, and the rate in England fell in between at 10 fires per 100,000.
- In Asia, China had double the rate of EV fires than in South Korea, but both countries reported similar rates for ICEV fires - between 16-19 fires per 100,000.
- FRNSW data showed EV fire rates on par with the Nordic countries, but ICEV fire rates were more similar to the Asian countries.

There are several factors that may contribute to the discrepancies in fire rates between EVs and ICEVs, and between rates for differing countries and regions, including:

- Age of vehicles and onset of battery cell ageing
- Quality of vehicles and charging equipment
- Care and maintenance
- Climatic and environmental conditions

Considering the number of EVs in the various jurisdictions and relative proportions of EVs in the vehicle fleets (Figure 7), it is apparent that the sheer number of EVs in China is a significant factor. When we consider that catastrophic battery cell failures are estimated to occur at a rate of one in every 10-40 million cells depending on quality[87], and that an average EV battery has between 3000-9000 battery cells, the potential for fires increases with the number of EVs in use and is likely to accelerate in proportion to uptake.

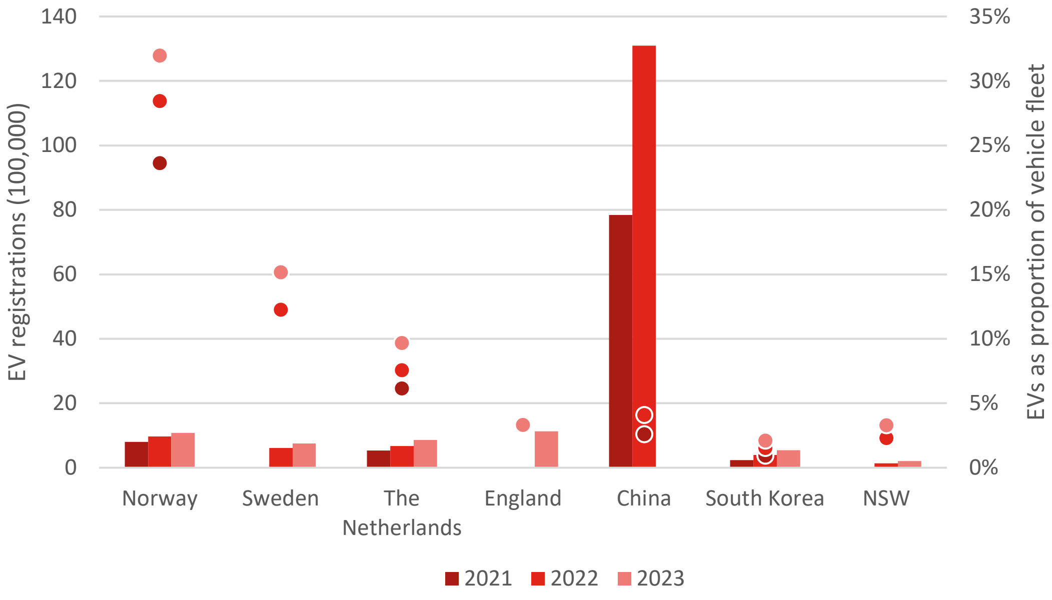

FIGURE 7 COMPARISON OF EV UPTAKE (COLUMNS REPRESENT EV REGISTRATIONS AND DOTS REPRESENT EV NUMBERS AS A PROPORTION OF THE ROAD VEHICLE FLEET) IN VARIOUS JURISDICTIONS BETWEEN 2021 AND 2023.

Overall, the findings show that more comprehensive and granular data is needed to be able to predict and plan for higher EV uptake in Australia, and that singular prevalence rates are not reliable indicators of risk. It is also important to note that EVs are likely to eventually replace most ICEVs in the vehicle fleet (unless other technologies overtake them) and that all fires involving these vehicles will potentially involve EV batteries.

SIGNIFICANT EV INCIDENTS ATTENDED IN NSW

While there have been few incidents in NSW to date, FRNSW and our partner agencies have responded to several challenging incidents involving EV batteries, as described below:

PENROSE 11 SEPTEMBER 2023

A BEV ran over some road debris from a truck on a highway causing the HV battery to immediately become compromised and ignite. The driver and passenger were able to escape the vehicle before alerting NSW Rural Fire Service (RFS) who arrived at a vehicle well alight. FRNSW HAZMAT was called to assist post-incident and were on scene for over 3 hours to monitor the vehicle for secondary ignition.

FIGURE 8 FOOTAGE AT THE SCENE OF THE FIRE AT PENROSE (SOURCE: NSW RFS)

MASCOT 11 SEPTEMBER 2023

A faulty HV traction battery went into thermal runaway after it was inappropriately stored in an open car yard in close proximity to other vehicles. The battery pack had been removed from the vehicle and kept on the ground underneath its front end. After a number of weeks exposed to the elements, the battery entered thermal runaway. The fire spread rapidly to the vehicle body and an additional four vehicles surrounding it before being extinguished by Airservices Australia and FRNSW, who continued to cool and monitor the battery afterwards. This incident occurred within 100 metres of the Airservices control tower at Sydney Airport.

FIGURE 9 AFTERMATH OF THE MASCOT FIRE IN SEPTEMBER 2023

BERKELEY VALE 14 MARCH 2024

In March 2024, FRNSW and NSW RFS crews attended a second-alarm fire involving the HV battery of an electric prime mover on charge at an industrial site. Crews were on scene for almost 6 hours to manage the incident, which required hazardous materials support to monitor the water runoff and contain the large battery pack after removal. This was the third incident that FRNSW had attended at the site where electric trucks were being built. The battery pack was similar to one that ignited while travelling on the West Gate Freeway in Melbourne in November 2023[88], causing the closure of an exit ramp and a section of the left lane of the freeway for over 12 hours.

ST MARYS 6 APRIL 2024

In April 2024, FRNSW firefighters responded to reports of an intense fire that was threatening nearby exposures at approximately 11:30 pm on a Saturday night. Information on what was stored on site was not available at the time, with incident commanders later finding hours into the incident that the third-alarm fire involved multiple faulty EV bus battery packs stored under tarpaulins in the yard of the electric bus manufacturing site.

The battery fire produced a highly alkaline and corrosive atmosphere and water run-off, requiring a 200-metre exclusion zone to be established. The batteries were later found to be solid-state lithium-metal polymer (LMP) batteries containing a lithium metal anode which reacts violently with water. Advice from the battery manufacturer received following the incident recommended that damaged batteries should be stored at -20°C for 24 hours to prevent further ignition. This incident took over 60 hours to manage on site.

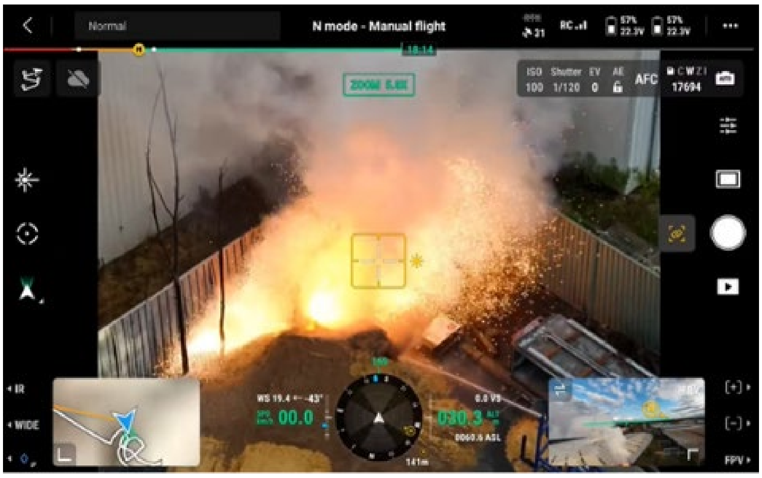

FIGURE 10 RPAS FOOTAGE SHOWING AN EXPLOSION REACTION OF THE LMP BATTERIES IN ST MARYS.

CAMPERDOWN 13 JUNE 2024

A firefighter suffered minor flash burns responding to an incident in which the cabin of a PHEV was smoke logged on arrival. The rear passenger door was opened, and a flashover occurred inside the cabin erupting in a “ball of flames” as described by crews.

Firefighters were unable to determine the model variant, and the vehicle could not be disconnected from the charger, further complicating the incident. An independent fire investigator later determined that the HV battery located within the transmission tunnel area of the vehicle was involved in this incident.

FIGURE 11 IMAGE FROM FOOTAGE CAPTURED AT THE SCENE IN CAMPERDOWN WHEN THE DOOR OF THE PHEV WAS OPENED AND FLAMES ERUPTED FROM THE VEHICLE CABIN.

EV FIRE INCIDENTS IN CARPARKS

When vehicles ignite in enclosed carparks, the risk of fire spread, and the build-up of smoke contribute to the complexity of the response for firefighters. When EVs are involved, there are additional complicating factors related to the electrical risks from charging, the large volumes of flammable vapours that can be produced, the risk of vapour explosion, the rapid fire development and directional flames that can contribute to fire spread to other vehicles and to building elements, the shielded nature of the fire due to the location of the HV battery, which may render fire sprinkler systems less effective if present, and the risk of secondary ignitions.

Some recent examples reported around the world have highlighted the complexities of managing EV fires in enclosed carparks and the specialist training, equipment, and resources that need to be coordinated for the response.

BRUSSELS 11 FEBRUARY 2022

On 11th February 2022 in Brussels (Belgium)[89,90], firefighters responded to reports of smoke in a restaurant, however discovered it was coming from a nearby underground parking garage. An electric vehicle was discovered burning on Level -3 (below ground), with no surrounding vehicles and was not on charge at the time. There was a large amount of heat and smoke and there was significant damage to the cables and conduits housed in the walls of the carpark. A private wrecker removed the vehicle from the carpark and it was lifted into a container where it was immersed in water to cool the battery.

FIGURE 12 (LEFT) BURNT OUT EV IN THE RAVENSTEIN STREET PARKING GARAGE IN BRUSSELS, AND (RIGHT) EV REMAINS BEING LIFTED INTO A CONTAINER TRUCK FOR IMMERSION (THE BRUSSEL TIMES, 15 FEBRUARY 2022[89]).

PRAGUE 4 MAY 2023

At 2356 hrs on 4th May 2023, a fire was detected at Level -2 in an underground carpark of an office building in Prague (Czech Republic)[91,92]. Firefighters could not find the source of the fire on that level however smoke was seen on CCTV cameras on Level -1. On survey, fine white smoke was seen issuing from an EV connected to charging on that level. The vehicle, a Jaguar i-Pace SUV, was the only vehicle parked on that level at the time. Shortly after the discovery, the vehicle chassis exploded, and this was followed by flaming and increased smoke production. There was zero visibility and firefighters had to use thermal imaging cameras for orientation, manually disconnecting the vehicle from charging. Firefighters could not gain access to the electrical switchboard to disconnect power to the building as the burning vehicle was blocking the path. They noted that the smoke extraction system had low effect.

A high-pressure water lance (Cobra Cold Cut System™) was deployed, and the fire was extinguished in 53 minutes using a total of 17,000 L of water from attack lines, and 2,000 L from the high-pressure cutting system. The vehicle was then raised onto a transport cart and moved into an emergency lift. Four (4) firefighters travelled in the lift with the vehicle, with self-contained breathing apparatus (SCBA) and portable fire extinguishers, while it was being raised to ground level and towed out of the lift. Electrolyte was leaking from the EV battery pack at the time.

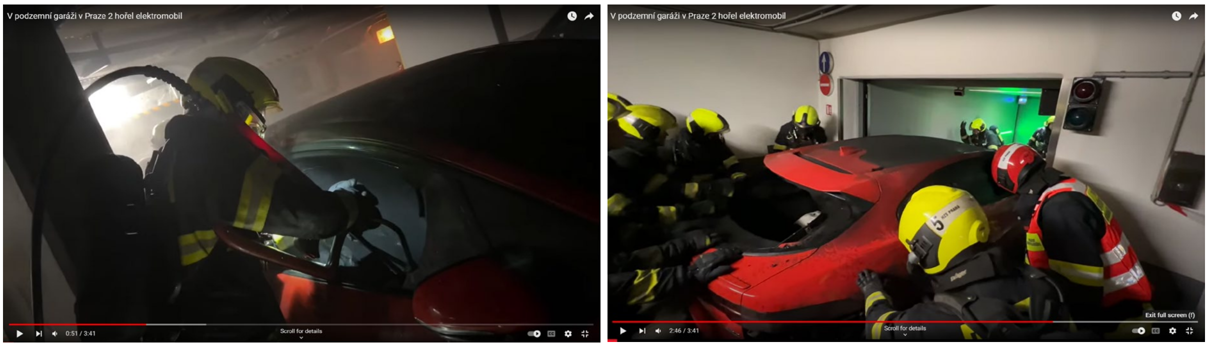

FIGURE 13 (LEFT) HASIČI PRAHA FIREFIGHTERS USING COBRA COLD CUT SYSTEM™ TO EXTINGUISH EV BATTERY FIRE[9292]; (RIGHT) HASIČI PRAHA FIREFIGHTERS MOVING THE EV INTO EMERGENCY LIFT[92]

Just after 0300 hrs the vehicle was then loaded by hydraulic arm into a container to be transported. The container was filled with 8,000 L of water and remained in the container until 12th May when it was then removed and handed to the owner's representative.

FIGURE 14 (LEFT) EV PLACED INTO IMMERSION CONTAINER[91]; AND, (RIGHT) EV BEING REMOVED FROM IMMERSION CONTAINER[91].

BURWOOD, NSW 20 SEPTEMBER 2023

An incident attended by FRNSW in September 2023 in a ground level car park of a commercial building demonstrated the potential for structural damage to buildings caused by LiB fires. On arrival at the scene, firefighters had zero visibility and could only find the seat of the fire from a soft glow within the carpark. They heard loud thumping noises near the fire, later finding that several large pieces of concrete, some over 20 kg in weight, had fallen from the ceiling. A LiB-powered golf cart had caught fire while charging on a trailer, resulting in severe concrete spalling to the 3.6-metre-high carpark ceiling above the battery compartment housing a 5 kWh system. The cylindrical LFP cells (33140 format) were vertically oriented in the battery housing venting directly upwards from the storage area of the cart.

Following this incident, FRNSW released an Operational Hazard Alert warning firefighters of the injury risk due to large and heavy falling debris, and potential structural failure in LiB fires.

FIGURE 15 PHOTOS SHOWING CONCRETE SPALLING ABOVE THE FIRE AFFECTED GOLF CART, WHICH CAUGHT FIRE IN BURWOOD, NSW IN SEPTEMBER 2023

HACKENSACK 8 MARCH 2024

At 0130 hrs on the 8th of March 2024, firefighters were called to an alarm on the lower-level parking garage of a six-storey apartment building in Hackensack, New Jersey (USA)[93,94]. On arrival, firefighters were met with thick smoke causing limited visibility but were able to locate the fire involving the EV and knocked it down quickly. They then continued cooling the EV battery for seven (7) hours before it could be safely removed from the building. One firefighter was injured during the response and was released from Hackensack Hospital overnight.

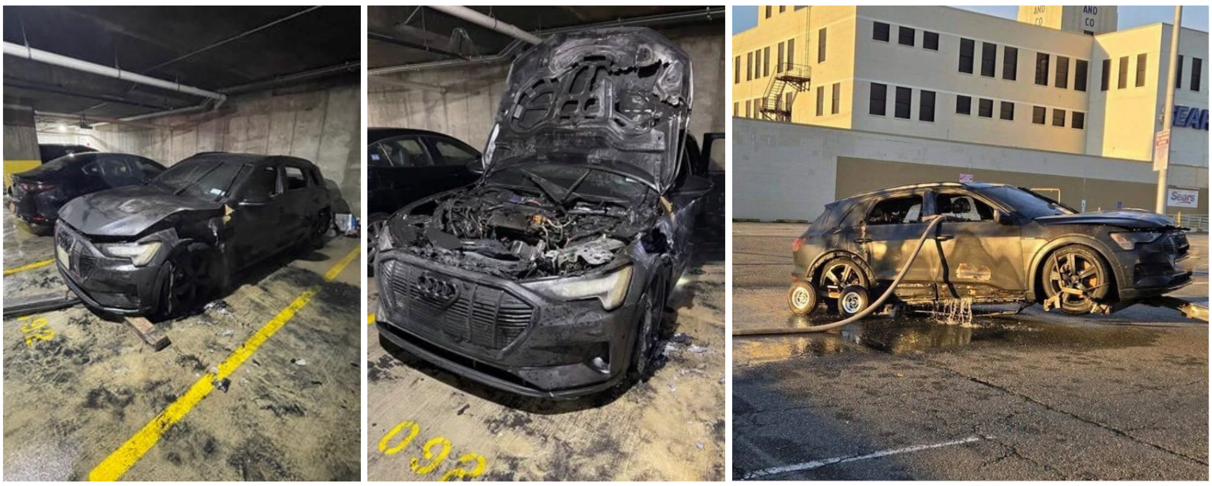

FIGURE 16 PHOTOGRAPHS[94] SHOWING THE EV FOLLOWING EXTINGUISHMENT AND COOLING BY HACKENSACK FIRE DEPARTMENT. EARLY AND SUSTAINED INTERVENTION PREVENTED FIRE SPREAD TO A NEIGHBOURING VEHICLE AND THE SURROUNDING STRUCTURE.

INCHEON 1 AUGUST 2024

A Mercedes-Benz EQE caught fire in the underground parking lot of an apartment complex in Incheon, South Korea at around 6:15am on the 1st of August 2024[19,]. The incident resulted in 21 people suffering smoke inhalation, including young children, 103 evacuations, and 106 people having to be rescued from stairs and balconies from the smoke. A reported total of 177 emergency responders were deployed, extinguishing the fire after 8 hours and 20 minutes[95]. Approximately 480 households were left without power and were relocated to temporary housing facilities[96].

The fire reportedly spread to 40 surrounding vehicles, with a further 100 vehicles suffering heat and soot damage[96]. The investigation is ongoing, however there were reports[97] that the pre-action sprinkler system was deactivated by a staff member from the apartment management office shortly after the fire alarm at 6:09 am. By the time the manual override button was released at 6:14 am, the wiring had been damaged, and the sprinkler system remained inactive, contributing to the rapid fire spread.

FIGURE 17 (LEFT) IMAGE FROM CCTV FOOTAGE SHOWING THE VEHICLE OF ORIGIN RELEASING PALE VAPOURS AS IT ENTERED THERMAL RUNAWAY, BEFORE FLAMES ERUPTED (SOURCE: KOREA JOONGANG DAILY 2024[19])19. THE VEHICLE WAS NOT ON CHARGE AT THE TIME AND THE OWNER REPORTED THAT THE VEHICLE HAD BEEN PARKED FOR THREE DAYS BEFORE THE FIRE WITHOUT ANY APPARENT ISSUES[97]. (RIGHT) AFTERMATH OF THE INCHEON APARTMENT CARPARK FIRE ON 1ST AUGUST 2024 (SOURCE: YONHAP NEWS 2024[96])

Dashcam footage salvaged from a vehicle damaged in the fire was released in September[98] revealing how the fire spread through the carpark. Several occupants tried unsuccessfully to attack the fire using portable extinguishers before flammable ceiling materials ignited and spread to other areas (Figure 18). The later report also revealed that the fire had burnt a total of 87 nearby vehicles, with damage to a further 783, and that 23 residents had suffered smoke inhalation injuries[98].

FIGURE 18 IMAGE FROM DASHCAM FOOTAGE SHOWING IGNITION OF CEILING PRODUCTS IN THE INCHEON CARPARK FIRE SOON AFTER THE FIRE BROKE OUT (SOURCE: NEWS 1 KOREA 2024[98])

This incident highlighted the importance of early intervention via systems such as automatic fire suppression and compartmentation in preventing fire spread in carpark settings.

OPERATIONAL NEEDS

With the growing number of EV types, models and variants available, emergency responders potentially must deal with a large variety of battery pack designs, chemistries, formats, capacities, configurations, and positions, and may require varying response procedures during any incidents involving these alternatively powered vehicles and products.

Fire and emergency service organisations need awareness of, and evidence-based procedures, equipment, and training for, high consequence incidents involving EVs, including RTCs and incidents in tunnels, and fires when parked in residential garages and multi-level carparks.

Some additional complexities in the management of EV fires include:

- Managing toxic and flammable vapours particularly in compartments such as garages and carparks, which are located under or adjacent to occupied areas, especially in domestic dwellings or residential buildings.
- Containment and recovery of large volumes of contaminated fire water runoff when the response to an EV fire involves extinguishment and extended cooling.
- Management of unknown hazardous materials - large amounts of toxic and flammable gases are released when EV batteries undergo thermal runaway. Detailed chemical composition of LiB cells and electrolytes are not routinely provided by product manufacturers, requiring emergency responders to treat incidents involving LiBs based on a worst-case scenario.
- Post incident management and handling of damaged or defective LiBs can expose workers from all industries involved in inspections and assessments, investigations, recovery, recycling, and waste disposal, etc., to associated risks and hazards. Following any incident where an EV battery has sustained damage or is indicating a fault, there is a risk of ignition hours, days or even weeks following the initial incident. Currently in NSW, there exists no clear and viable process for the management, inspection, or disposal/recycling of damaged LiBs of any size.
- The safe removal of fire impacted EVs from underground or multi-deck parking facilities is a particular challenge. Due to the risk of secondary ignition, EVs must be removed in a timely manner to facilitate recovery and reoccupation of buildings. Vehicle recovery operators must be able to access low-height carpark facilities, provide adequate personal protective clothing and equipment for their drivers, and be willing to carry the risk of exposure to secondary ignition and potential damage to their recovery vehicle in providing suitable services.

It is the experience of FRNSW that some parts of the automotive industry may not be aware of the fire/thermal runaway risks of LiBs in EVs. Safety training for the industry focusses mainly on electrical safety, specifically how to work around HV components and how to safely connect/disconnect the HV battery but does not appear to include training on awareness of the thermal runaway risks, identifying warning signs of damaged LiBs, safe handling and storage, or actions to take when batteries undergo thermal runaway. For example, in January 2021, FRNSW crews responded to an incident in Fairfield East where a damaged EV was unwittingly placed in a vehicle crusher resulting in ignition of the HV battery. The vehicle was removed from the equipment after initial extinguishment and placed on a concrete pad where the battery continued to ignite. Full extinguishment was achieved after approximately 45 minutes with machinery used to pull apart the vehicle for better access to the cells.

TRAINING

Training emergency responders on EV awareness and response is a significant challenge as EV incidents may be encountered by police, ambulance, volunteer rescue agencies, fire services and recovery operators. It is important that all first and second responders understand the hazards and risks that may be present when dealing with EVs.

To address the knowledge gaps amongst emergency responders, FRNSW, in collaboration with TAFE NSW, has developed an online training package to raise awareness of EV hazards and risks, and guidelines to work safely around EVs. While this preliminary work has been successful, further development is required to expand the training materials to cover the variety of scenarios that might be encountered by responders. There is a need for practical training for firefighters when responding to incidents involving EVs, especially in responding to scenarios that involve LiB thermal runaway, vapour cloud explosions (VCE), RTCs involving trapped occupants and battery failure, EV incidents while connected to charging, e-bus and e-truck fires, FCEV fires, incidents involving bidirectional charging of EVs, and EVs affected by flood waters. The training must be evidence-based and informed by rigorous research.

EMERGENCY INFORMATION

Accurate information regarding the location of the HV battery, HV cabling, and HV components, immobilisation/disconnection procedures, specific hazards, and response requirements can be critical during emergencies involving EVs. Emergency responders need ready access to clear, concise and complete information on each model and variant of EV, including e-trucks and e-buses, in the form of Rescue Sheets[99] and Emergency Response Guides (ERGs)[100]. These guides are needed to ensure the safety of responders and to minimise delays when managing complex EV incidents, particularly when extrication of injured occupants is required. FRNSW has now made Rescue Cards available on fire appliance Mobile Data Terminals (MDTs) to allow crews the ability to look up vehicle information quickly at incidents to minimise intervention delays. Currently not all vehicle makes and models have available documentation. Regulation is required to ensure that all road-registered EV models and variants have up-to-date information available for use by emergency responders.

PERSONAL PROTECTIVE EQUIPMENT AND CLOTHING (PPE/PPC)

Firefighters heavily rely on their PPE and PPC, including turnout gear (structural firefighting uniform), self-contained breathing apparatus (SCBA), and splash suits, to minimise health and safety risks in fires and HAZMAT incidents. The effectiveness of current firefighting PPE and PPC against the products of combustion and thermal hazards of LiBs in thermal runaway are not clear. FRNSW is monitoring data on injuries and damage to gear, including firefighting gloves and boots, after use in LiB fires. Additionally, firefighters generally use electrical insulating gloves rated to maximum voltages of 500 Vac and 750 Vdc (IEC 60903 Class 00), designed to insulate against typical domestic circuits. These may not be suitable for the higher voltages present in some EVs and charging equipment. Research and testing are required to ensure that PPE and PPC used by NSW firefighters, and the decontamination and laundering processes used to clean their gear, remain fit for purpose.

HAZMAT DETECTION EQUIPMENT

As the combat agency for hazardous material incidents across NSW, FRNSW is reviewing its current instruments and equipment for effectiveness when monitoring EV and LiB fires, including equipment used in atmospheric monitoring and water runoff testing.

DC VOLTAGE DETECTION TOOLS

Exposure to HV electricity can cause burns, electric shock, and fatal injuries. EVs incorporate several features that are designed to contain the hazardous electrical energy to the vehicle battery, however hazardous electricity may still present if these features fail or workers are exposed to the energy within the battery which cannot be removed. FRNSW is undertaking a trial of a non-contact DC voltage detector which, if effective, would allow emergency responders to identify the presence of hazardous DC electricity in and around an EV. FRNSW currently carries alternating current (AC) voltage detectors which do not detect direct current (DC) electricity.

EV IMMOBILISATION AND STABILISATION

Unexpected vehicle movement is a serious hazard that has led to responders being injured. This can occur due to the silent operation of EVs and responders not recognising that the vehicle is running due to an absence of engine noise. Failure to effectively switch off the vehicle means if the accelerator is inadvertently pressed, or features such as “self-parking mode” are activated, the vehicle may move forwards or backwards with a large amount of torque, injuring responders, occupants or bystanders at the incident scene. FRNSW is currently investigating a number of options to minimise this risk including an EV arresting plug designed to immobilise plug-in EVs by tricking the vehicle software into thinking it is on charge. Additionally due to the added weight of the HV battery and a lower centre of mass in EVs, techniques and tools to aid in stabilisation before and during extrication are required.

EV RECOVERY EQUIPMENT

Due to the risk of secondary ignitions, fire-affected EVs must be promptly removed from buildings to a safe area away from exposures. When EV fires occur on roadways or tunnels, prolonged extinguishment and cooling operations can have serious impacts on traffic along major transport routes. There are a number of considerations in the safe removal of EVs from (particularly underground) carparks, including safety of recovery operators, access and height restrictions, lifting capabilities (dragging vehicles may damage additional battery cells or activate the regenerative braking system to charge the battery) and fire resistance of the structure.

FRNSW is supporting Transport for NSW (TfNSW) in developing an EV fire containment system and response capability as an interim measure before a comprehensive recovery service is established to cover the state. The system under development includes a large trailer that has been modified to allow an EV to be loaded into a container and immersed in water. Future systems will need to cater for recovery of e-buses and e-trucks.

OTHER EQUIPMENT, TOOLS AND INNOVATIONS

FRNSW is keen to investigate the effectiveness and feasibility of using innovations such as novel extinguishing agents and delivery systems, fire blankets, undercar cooling nozzles or pancake nozzles, high-pressure water blades or cutting extinguishers, and piercing nozzles in EV fires. Additionally, the use of remotely operated firefighting equipment can facilitate operations in structure fires where EVs, LiBs or other hazards may make the area untenable or unsafe for firefighters due to risks such as structural collapse, explosion or extreme heat.

FRNSW is cognisant that some equipment may create additional hazards at an EV incident. Methodologically rigorous assessment and testing is required to ensure the suitability of any new equipment or products, and to inform the development of appropriate procedures and training for responders in their use.

FIRE SAFETY IN BUILDINGS

In the built environment, AFAC and FRNSW have been strongly advocating for fire protection measures that will assist firefighting operations in the event of vehicle fires in parking areas. Some important considerations include:

- Early smoke and heat detection in all areas, but especially in areas where EVs are parked or charged.
- Automatic shutdown of EV charging facilities upon activation of alarm and facility for fire services to remotely isolate EV charging
- Automatic notification to the fire service
- Automatic emergency ventilation / smoke hazard management in parking areas to remove toxic and flammable vapours, fire gases and smoke
- Automatic fire sprinkler systems in all parking areas to minimise fire spread and protect structural building elements
- Availability and adequacy of firefighting water on site
- CCTV in all areas to assist with situational awareness, firefighting intervention, and subsequent investigations
- Adequate fire resistance and compartmentation to limit fire spread
- Onsite facilities to capture and recover contaminated water runoff
- Onsite Emergency Services Information Package[101]
- Consideration in the design to allow adequate access and timely removal of vehicles from the building
- Consideration in the design of impacts of EV parking and other risks, such as parking and charging facilities for e-micromobility devices (e.g. e-bikes, e-scooters and e-mobility aids) and energy storage systems, on building services, evacuation routes and emergency access.

While these considerations may be readily achievable in new structures, it is noted that the implementation of these measures in existing buildings may understandably be more challenging and costly.

While some of the above measures are specifically to address EV risks, FRNSWs position remains consistent for all carparks housing modern vehicles.

RESEARCH NEEDS

In fire research, full-scale fire testing of realistic fire scenarios can be used to help understand and assess the behaviours and effects of fire on occupants, buildings and the surrounding environment. Full-scale experimental studies of vehicle fires are limited due to the complexities of testing, safety and environmental considerations, and costs. When small and disparate series of tests are conducted using different vehicles or vehicle surrogates under limited configurations, using different test apparatus, methodologies, parameters and conditions, results are difficult to contextualise and compare.

Some available research has indicated that the measured heat release rates (HRRs) in EV fires are comparable to that in ICEV fires, giving rise to conclusions being drawn that EVs pose no significant increased risk in fires[24,102]. However, the nature of such tests is critical to consider in making such conclusions.

Currently a number of different fire tests have been undertaken internationally to simulate vehicle fires involving LiBs under various abuse conditions. These have involved the use of different battery packs, mock EVs, rebuilt EVs from original gasoline vehicles, and actual EVs. Not only do the methods of simulating EV fires vary, however so do the objectives of the tests. A summary of experimental studies reviewed has been provided in Appendix B.

In reviewing such literature, FRNSW has adopted several considerations when comparing results from published experiments:

1. **Test vehicles used**

   Equivalent or comparable vehicle models should be used in comparative testing of EVs and ICEVs to minimise the variations due to design, quality, and construction.

   Mock-vehicles and mock-battery packs used in some experiments are not likely to behave in a similar fashion to production vehicles and equipment during a fire, with likely differences in fire propagation and size.

2. **Test initiation method**

   How the vehicle fires are initiated or how thermal runaway is induced in testing may significantly affect fire development and results. There are wide variations between experimental set ups, with some vehicle fires initiated using gas burners or fuel pool fires, and thermal runaway being induced using external heating elements, nail penetration or short-circuit, and overcharge. Where the fire is initiated relative to the location of the battery and/or fuel tank will also affect fire development.

3. **Test conditions**

   The test conditions, including atmospheric conditions, test enclosure design, ventilation, windows and doors, will all affect fire development.

4. **Battery conditions**

   Battery pack design, capacity, format, chemistry, SoC, and state of health (SoH) can all affect the outputs during thermal runaway. How much of the battery pack becomes involved or is consumed in the fire will also affect the results. Battery fires may produce a number of HRR peaks related to the sequential failure of individual battery cells or modules.

5. **Test parameters and measurement approaches**

   HRR, including pHRR and THR, is commonly used to compare the thermal hazards of EV and ICEV fires. LiB cells in thermal runaway can produce highly directional jet-like flames depending on battery pack design and the orientation of vents. These behaviours differ from fires involving common fuels. Oxygen consumption calorimetry (OCC) is a standard method used in measuring HRR in large fires, however it is known to underestimate the contribution from the stored energy in LiB cells[103,104,105]. The uncertainty in measurement renders direct comparisons unreliable.

In analysing the fire safety of EVs in structures, appropriate and accurate measurement of all potential hazards is critical. Gas temperatures, radiative heat flux, pressure and volume of vapours and gases produced, and their flammability and toxicity, are parameters that should be prioritised in all testing of LiBs and EVs.

6. Repeatability

Fire tests can produce variable results even when all the controllable variables are accounted for. Tests may be reproducible but may not produce repeatable results. Single tests may not be representative of the potential for damage and repeat tests are often necessary. This also appears to be even more critical in battery fire tests.

FRNSW has proposed a comprehensive program of real fire tests to address the knowledge gaps identified in LiB and EV fires. The Safety of Alternative and Renewable Energy Technologies (SARET) Research Program is a collaborative program of research that focuses on fire service response and mitigation strategies to manage incidents involving LiBs in a variety of applications[106]. The research and testing program includes four main projects:

1. Fire service response to lithium-ion battery fires
2. End-of-life lithium-ion battery hazard management
3. Electric vehicle fires in structures
4. Fire propagation in battery energy storage systems

The program aims to inform operational procedures, new equipment and training for firefighters and fire safety requirements for buildings and infrastructure housing these technologies, in an Australian context. Our ongoing research will assist FRNSW and our partner fire and emergency service organisations across Australia in actively supporting the safe integration of EVs into the vehicle and transport fleet. FRNSW is committed to ensuring the safety of firefighters and the public by prioritising research to inform prevention and education, and to prepare our people for any response. This is not possible without adequate resources and funding for research, equipment, and training. The SARET initiative is a means to overcome the shortfalls, avoid duplication of effort, and maximise our research output and return.

Alongside this important research, FRNSW continues to work closely with other state and federal government agencies, industry stakeholders, and AFAC partner agencies to develop prevention strategies and to ensure training and responses incorporate new learnings and changes in alternative and renewable energy technology hazards. This includes:

- Work and advocacy to mandate the use of EV registration plate stickers to help emergency responders identify EVs and FCEVs, and the provision of rescue sheets and ERGs to assist during emergencies.
- Representation on the AFAC Alternative and Renewable Energy Technologies (ARET) technical group and contribution to the development of key national guidance documents.
- The publication and sharing of interim operational advice for dealing with LiB failure to maximise work health and safety for operational firefighters.
- Conducting and sharing results of initial trials of various tools and equipment.

- Working collaboratively with stakeholders, including:
  - Electricity network service providers (ENSPs) to provide advice and plan for incidents as EV charging infrastructure and LiB energy storage systems are integrated into the electrical network.
  - Waste, recovery and recycling industries, and transport authorities (including TfNSW) to establish systems to safely and efficiently remove damaged EVs from road networks and buildings.
  - Regulators including the Australian Competition and Consumer Commission (ACCC), NSW Fair Trading and SafeWork NSW to monitor and share data and learnings from incidents, and to provide advice on community education on fires involving LiB-powered devices and equipment.
  - NSW Environmental Protection Authority (EPA), local councils, and service providers to develop policy and solutions to safely dispose of damaged LiBs.
  - Government agencies including NSW Fair Trading, SafeWork NSW, NSW EPA and Transport for NSW in providing consistent and impactful community messaging and education through a range of media to reduce the incidence and consequence of LiB-related fires.
- Advocating for and contributing to improved regulation, codes, and standards to support a safer clean energy transition.

SUMMARY

A safe transition towards cleaner alternative and renewable energy sources, requires consideration of the safety of the community and emergency responders who are tasked with responding when incidents involving these technologies occur.

The prevalence of EV fires is currently low in most jurisdictions in comparison with fires involving traditional fuelled vehicles, however fire and emergency services have identified a number of operational needs and research and knowledge gaps that need to be addressed with urgency as the electrification of the vehicle fleet accelerates worldwide.

The unique hazards associated with LiBs, including thermal runaway, vapour cloud ignition, extreme fire behaviour, stranded electrical energy, electrical risks from charging, extinguishment challenges, toxic emissions and fire effluents and secondary ignitions, all render EV incidents more challenging for emergency responders, requiring extra precautions, resources and training to safely and effectively manage them.

As the current DtS clauses in the NCC do not adequately address the special problems of firefighting associated with EVs, FRNSW considers the E1D17 and E2D21 special hazard provisions in NCC 2022 to be appropriate for application to EV parking and charging in buildings. These ‘special hazards’ clauses require consideration of special characteristics of the building or use of the building that require additional mitigating measures to facilitate safe fire brigade intervention due to the DtS Provisions not adequately addressing the risk. The position is informed by current knowledge and as the research and evidence continues to develop, FRNSW’s position will evolve as appropriate.

APPENDIX A FRNSW POSITION STATEMENT VER 02

FIRE + RESCUE

POSITION STATEMENT SUMMARY

Electric vehicles (EV) and EV charging equipment

Position

Effective 4 June 2024, the following is a position of Fire and Rescue NSW (FRNSW):

FRNSW endorse the position on *Electric Vehicles (EV) and EV charging equipment in the built environment* as published by the Australasian Fire and Emergency Service Authorities Council (AFAC), as the appropriate guidance to practitioners who design and certify any Class 2-9 building that incorporates EV parking and/or charging.

FRNSW consider EVs and EV charging stations to be special hazards under E1D17 and E2D21 of the *National Construction Code* (NCC) 2022. As such, the certifier should identify what additional provisions are being provided, if any, and whether the fire safety measures in the building are commensurate to the hazards and risk(s) associated with the proposed EV parking and/or charging, when certifying any related building application.

Note: FRNSW considers incidents involving electric vehicles (EVs) and EV infrastructure to currently be low frequency, but potentially high consequence, incidents that require enhanced fire safety measures in place to facilitate safe and effective fire brigade operations.

FRNSW consider that all aspects of the AFAC Position should be considered and addressed. In conjunction with the AFAC position, FRNSW recommend that EV parking and/or charging be:

- located externally or in open air where possible.
- if located internal to a building, the carparking area should:
  - be protected by an automatic fire sprinkler system with a performance equivalent to a system complying with AS 2118.1 or AS 2118.6; and
  - not apply concessions to fire resistance levels (FRLs) that may be provided within the NCC deemed-to-satisfy provisions.
- protected by fire hydrant coverage.

Any request for consultation or referral to FRNSW relating to any building that intends to incorporate EV parking and/or charging, should adequately identify the hazards and risks and demonstrate how they are being addressed within the design. The 'recognised person' should address the special hazards and how the provisions of this position statement and the AFAC Position have been considered and addressed.

Note: A 'recognised person' means a person who is both an accredited practitioner (fire safety) and a fire safety engineer under the *Environmental Planning and Assessment (Development Certification and Fire Safety) Regulation 2021*.

Reference must be made to the FRNSW website to ensure this position is current at the time of use, and this position has not been superseded or revoked.

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VER 02 – JUN 2024

NSW GOVERNMENT

Position Statement Summary
Electric vehicles (EV) and EV charging equipment

Summary

This position statement supersedes the previous position last updated on 29 April 2024.

This position statement is based on FRNSW review of literature found to-date on the risks of EVs and EV charging. Whilst the incident rate may currently be low, the potential consequences when the lithium-ion battery pack of an EV is involved in a fire, whether or not the fire originated from it, are not fully understood and present a different challenge to fire fighters, occupant life safety, building integrity and environmental impacts when compared to an internal combustion engine vehicle (ICEV).

Some of the differences that need to be accounted for include; the potential for a rapidly developing fire, jet like flames, longer burn times and the potential for vapour cloud explosions. The failure of lithium-ion batteries during a fire is unique and differs from the typical combustion process of other combustible materials, and this difference also needs to be better understood and considered. The research and testing undertaken on EVs is considered to be quite limited and FRNSW consider that there are still considerable knowledge gaps.

It is evident from incidents that involve lithium-ion batteries that the managing of these incidents can be protracted, and there is also the potential for secondary ignition of battery cells even after initial extinguishment actions.

This position statement directs building proponents to the AFAC position as appropriate guidance in the design and certification of buildings that intend to incorporate EV parking and/or EV charging equipment.

This position reiterates the AFAC position that surveyors and certifiers implement Clause E1D17 and Clause E2D21 of the NCC, in relation to special hazards, when assessing building applications. A failure event within an EV battery (such as mechanical, thermal abuse, rapid discharge, or internal cell failure) has the potential to lead to a thermal runaway event within the EV battery, which may pose significant challenges for the building structure, the building occupants and for firefighters in the management of the incident.

The position directs building proponents to address design considerations from the AFAC position, including active fire safety systems such as an appropriate automatic fire sprinkler system, and suitable fire resistance levels. This is largely based on the concerns raised above with regards to the limited testing and understanding of the consequences of fires involving EVs.

When requesting consultation with, or a referral to, FRNSW for any building incorporating EV parking and/or charging, the position requires a ‘recognised person’ to:

- identify hazards and associated risks in relation to EV parking and associated EV charging infrastructure
- demonstrate how the identified special hazards and risks are being addressed.

Informative commentary clarifies a ‘recognised person’ is as defined under Schedule 2 of the *EP&A(DCFS) Regulation*.

This position statement has been authorised for release by Chief Superintendent Fire Safety, FRNSW.

Contact us

For further information contact the Fire Safety Branch on (02) 9742 7434 or email firesafety@fire.nsw.gov.au.

APPENDIX B SUMMARY OF TESTS REVIEWED

TABLE 9 A SUMMARY OF TEST CONDITIONS AND CHARACTERISTICS FROM THE REPORTED FULL-SCALE EV OR/AND LIB PACK EXPERIMENTAL STUDIES.

Author	Test Level	Outdoor /indoor	Test specimens	Test setup	Test method	Parameters measured	Objectives
Lecocq at al. [107]	Module Real BEV	Indoor	2 modulars, one free burn & the other with firefighting operation a full battery pack with late firefighting operation EVs of 100% SOC (manufacturer 1 & 2) Diesel vehicles of full gas tank (manufacturer 1 & 2) All supplied by two French car manufacturers		Thermal runaway initiated by a gas burner on for 1min, orientated to the left front seat, inside the passenger cell, open windows.	- thermal flux - temperature - smoke temp, - flow rate - video & thermal IR camera, - online gas analysis	To quantify emitted gases and energies of full-scale BEVs and diesel-powered vehicles fires.
Watanabe at al.[108]	Full-scale BEV (Nissan Leaf 2011) & gasoline (Honda Fit 2003)	Indoor room (15x15x15m), free burn of vehicles on weighting platform	Leaf: LiB consists of 48 modules each containing 4 pouch cells & provided 360V DC and 24 kWh. Fit: a plastic tank (10L) gasoline installed beneath the driver seat & front passenger. The door windows closed, the e-motor or engine shut off		Ignition initiated at the fully integrated soft rear bumper of the Leaf & at the left-side soft rear splash guard of the Fit with 80g of alcohol gel fuel	Temperature Mass loss rate Heat flux	To evaluate the fire risk of the EVs, flame propagation, the HRR & radiation heat flux of full-scale BEVs and gasoline powered vehicle
Lam, et al. [109]	Full-scale ICEV, PHEV, BEV fires	Indoor, free burn	7 full-scale fire tests, 30min duration, with the exhaust hood system located above the vehicle Battery A is designed for a PHEV while Battery B for extended range electric vehicle	The test area situated under a 6x6 m exhaust hood connected to an exhaust fan system, which was used to collect the smoke and hot gases produced by the fire. A 2.4 m by 1.2 m propane sand burner (itself to produce 2 MW fire with temperature around 800°C) was used to generate the fire exposure to the vehicle, simulating pool fire underneath the vehicle. The flow of propane was distributed over the entire burner surface.		temperature Heat flux Battery voltage Smoke & hot gases: (HRR, CO2, CO, HCN, HF & HCl)	To compare fire risk from BEVs, PHEVs & ICEVs under exposure to external fire conditions simulating a fuel spill fire.
Willstrand et al. [110]	Full-scale BEV & ICEV	Indoor	ICEV-A: full-size van BEV-A: full-size van with pouch cells BEV-B: small family car with prismatic cells	inside a fire hall with a large calorimeter hood above EV: gas burner of 30 kW placed underneath the battery pack ICEV: a small diesel pool fire located directly underneath its fuel tank		Oxygen, CO, CO2 concentration, mass flow of the extracted combustion gases Thermocouple Plate thermometers.	To compare fire behaviour of BEV & ICEV, FDS modelling of enclosure carparks to simulate toxic gas concentration, compare with health exposure limits.

Author	Test Level	Outdoor /indoor	Test specimens	Test setup	Test method	Parameters measured	Objectives
Long et al. [111]	pack, mock-up EV 100% of SOC	Free burn: indoor Full-scale burn: outdoor	1. free burn testing: 2. full-scale suppression testing: with A1, A2, B1, B2 battery only & Battery A3, B3 battery and interior components	Battery A 4.4 kWh under the rear cargo compartment Battery B 16 kWh under the vehicle floor pan. The gas (propane) burners were located under the vehicle to simulate a moderate size gasoline pool fire underneath the battery pack.		heat fluxes; products of combustion; temperatures; projectile; cell voltage; temperature thermal imaging; still photography; HD video; suppression water sampling; volume of suppression water flow; nozzle & chassis voltage & current;	To develop the technical basis of best practices for emergency response procedures for EV incidents, including suppression methods and agents; personal protective equipment (PPE); and clean-up/ overhaul operations.
Boe et al. [112]	full-scale rebuilt EV	Outside	The battery (26 kWh, 60% SOC) consisted of 12 modules, each containing 30 cells of pouch type of a Li-ion battery with NMC-cathode.	2 EVs used in the tests, originally gasoline cars, rebuilt to EVs by replacing the fuel tank & the engine with an electro-motor & a battery pack.	Test 1: Drop the EV from 20m high with the rear end downwards, & the speed hit the ground appr 70 km/h Test 2: Expose to an external heat source	Thermocouples positioned on the surface of the protective casing of the battery, Several Cameras	To check if heavy car crash induces thermal runaway and fire in an EV battery & how much water needed to extinguish an EV fire, in which the battery has reached thermal runaway.
Truchot et al. [113]	Combustible items of a commercial car Full-scale cars of ICEV and BEV	Indoor in the same facility as Lecocq at al. [107]		6 kW propane burner		Toxic products measured with both an online method, based on a FTIR spectrometer & with integral method.	Issues addressed in context of tunnels. To evaluate the impact of modern car evolutions, to review emission factors regarding both the nature of toxic compounds generated & through a CO equivalent factor using the FED & FEC relation
Bisschop et al. [114], Willstrand [115]	Pack	Indoor	Modules, including live & dummy modules packed inside a test container	7 tests, with variables ranged from suppression agents internal/external, activation time & duration.	Thermal runaway initiated in one battery module by impinging on one of its cells with the flame of a gas burner	Thermocouples	To evaluate the performance and applicability of commercially available fixed fire suppression system in controlling thermal events within the battery

Author	Test Level	Outdoor /indoor	Test specimens	Test setup	Test method	Parameters measured	Objectives
Li et al. [116]	Mock EV	Indoor	Prismatic Li-ion B cells packed into modules & sealed in pack, no other combustibles. Full Battery Pack with Chassis inside car shell		The triggered module overcharged at 1 ºC rate until the occurrence of thermal runaway.	Thermocouples	To explore the process that flame spread over the electric vehicle and evaluating the fire hazards of the electric vehicle
Kutschenreuter, et al. [117]	Modules/ packs	Indoor (4x4x2 with calorimeter on the roof	Type A: cylindrical Type B: prismatic	A: 12 cells per module B: 132 cells per module	Series 1: by mechanical drilling of one cell Series 1: by forced electrical overcharging	Thermocouple, oxygen consumption calorimetry, Toxic gases	Series 1: the burning behaviour to fill the identified knowledge gap in this field. Series 2: Using common commercial detection systems and suppression agents to minimize the risks caused by LiB.
Kang et al. [118], etc. [78]	Full-scale BEVs, ICEV and FCEV	Indoor (open space) using 10 MW-scale OCC	3 BEVs (1 tested LiB pack & body, separately), 1 ICEV, 1 FCEV	LiB pack (64.1 kWh), BEV (64.1 kWh): heating a surface of single cell using a heating sheet (575w) BEV (39.2 kWh) & BEV body: heating the vehicles' bottom boundaries using a propane burner (300kW) ICEV & FCEV: heating combustible contents of vehicles using a pan of heptane (300kW)		Load cells, thermal couples (inside the pack, LiB case, BEV body, fire plumes at height of 1.27m & 2.27m), voltmeter, heat flux sensors, HRR (using OCC & FCC)	To examine the thermal characteristic differences between BEV, ICEV, and FCEV, estimate the average effective heat of combustion of BEV fires
Petit Boulanger et al. [119]	Full-scale cars	Indoor in a facility of 19x19x2.9m	Test 2 (comparison): ICEV: Fluence (50L diesel) EV: Fluence Z.E. (400V, 100%SOC)	Test 1 (EV fire behaviour): EV: Kangoo Z.E. (400V, 100%SOC) EV: Fluence Z.E. (400V, 100%SOC)	Test 1: a 15 mins exposure to an aluminium pan of filled with 150 L alcohol under the car Test 2: start from the driver seat with a gas burner	Test 1: temperature Test 2: HRR, emitted gases	Efficiently identify EV Get EV safe easily Keep low the Li-Ion battery effect on extrication and extinguishing situations Create common standards to help first responders' decision Train first responders

Author	Test Level	Outdoor /indoor	Test specimens	Test setup	Test method	Parameters measured	Objectives
Sturm et al. [120] Sturm et al. [121]	Full-scale BEVs and ICEVs	Indoor (Tunnel)	3 BEVs and 3 ICEVs	BEV01/MNC: fire blanket BEV02/LMO: No BEV03/MNC: extinguishing lance	BEV02: Gas burner underneath the vehicle BEV01 & BEV03: Flooding the battery case with NaClaq ICEV01: the front interior ICEV02: the engine compartment	- voltage - battery temp - mass loss - air temp, - flow rate - video & thermal IR camera, - internal pressure - online gas analysis - heavy metals	The temperature development and distribution, smoke gas composition and its quantity and distribution, how to fight EV fires in the tunnel. A numerical modelling developed for simulating the effects of EV & eBus battery fire in tunnel systems based on test results.
Cui et al. [122]	Full-scale battery pack in EVs	Outdoor	full-size commercial battery pack of 1320 18650-type batteries connected, divided into six layers, each containing 220 cells	2 tests suppressed with water, other 2 with compress air foam	TR triggered through two electric heaters, each at constant power of 450 W	Thermocouples:	The fire propagation behaviour from both the battery pack level and the vehicle level, firefighting tests evaluated the fire extinguishing efficiency of different types of EVFE.
Quant et al. [123], Hynynen et al. [124], Hynynen et al. [125]	Car without energy storage (free burn), battery pack (NMC), Full-scale ICEV, BEV	Indoor Last 3 tests, have 10mm/min water applied at HRR of 1MW	Battery pack & BEV has a capacity of NMC 50 kWh, ICEV has 20L in fuel tank and 20L in a tray below the taank to simulate pool fire	As per Willstrand et al.[110], a 2x5x0.15m tray under test objects to collect water from sptinkler	A propane gas burner of 30kW at the rear of battery pack, keep on igniting flammable gases to minimise the risk of gas explosion.	HRR, THR, smoke & gas emission (not detail in the paper), VOCs, PAHs, HX, soot particulates from run-off water	Analyse run-off water (extinguishing) from fire test for inorganic and organic pollutants, including particle-bound PAHs, VOCs, soot content. the acute toxicity.
Arvidson et al. [126]	Full-scale BEVs (Li-NMC), and ICEVs	Indoor test with 5m ceiling height for ro-ro spaces,	2 2022 SUV BEVs with total of 82 and 50 kWh, charged to 90% SOC 2 2022 SUV ICEVs with 90% fuel	6 tray 2.5x1.0x0.15m with 75mm water placed on floor to simulate fuel pool fire. 4 water spray nozzles used in the tests, which activated at 1st HRR peak & lasted for 30 mins at 10mm/min.	ICEV: ignite fuel from plastic tank flow over to water surface of trays. BEV: Nail penetration into one of module.	HRR, THR, heat flux, gas temperature above the vehicle, surface temperature of target screens at sides of the vehicle	Compare fire behaviour of BEVs and ICEVs with water spray fire suppression

Author	Test Level	Outdoor /indoor	Test specimens	Test setup	Test method	Parameters measured	Objectives
Funk et al. [127]	Full-scale BEVs surrounded 8 by ICEVs	In a two open sided enclosure	7xRenault Fluence (NMC, 22 kWh, 2012), 1xTesla Model 3 (LFP, 55 kWh, 2021), 1x Nissan Leaf (NMC, 24 kWh, 2013)	BEV in the centre with distance of 0.2m btw head & rear and 0.4m btw sides from adjacent vehicles, ~0.3m btw the ceiling & the top of vehicles	short-circuiting the battery with an accelerator if hard to ignite, overcharge	Temperature (thermal couple, plate thermometer, optical smoke, DASPOS gas, HF electrochemical detectors, Concilium aspiration air intake	Investigate effectiveness of firefighting techniques and fire dynamics of electric cars in an open-sided enclosure
Cui et al. [128]	Full-scale BEV & PHEV in parallel	Outdoor	BEV (NMC, 38.1 kWh) PHEV (unknown, 13 kWh, 50L fuel tank)	0.6m of the distance btw two vehicles	heating power (at constant 3 kW) of the furnace underneath BEV, turn off on visible fire	Temperature, heat flux	Burning behaviour of two parallel parked EVs

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